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NASA-CR-167390

# EXTRAVEHICULAR CREWMAN WORK SYSTEM (ECWS) STUDY PROGRAM

## PREBREATHE ELIMINATION STUDY FINAL REPORT

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# EXTRAVEHICULAR CREWMAN WORK SYSTEM (ECWS) STUDY PROGRAM

## PREBREATHE ELIMINATION STUDY FINAL REPORT

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August 1981

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## FOREWORD

The ECWS Prebreathe Elimination Study identifies changes to the Space Transportation System required if prebreathing with pure $O_2$ prior to EVA is to be eliminated during operational flights.

This study has been performed under contract by Hamilton Standard for the National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, over the period from November 1981 to August 1981.

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## ABSTRACT

Prebreathe Elimination Study examines impacts of changing Orbiter cabin pressure and EMU EVA pressure to eliminate pure $O_2$ prebreathing prior to EVA. The investigation defines circumscribing physiological boundaries and identifies changes required within Orbiter to reduce cabin pressure. The study also identifies payload impacts, payload flight assignment constraints, and impacts upon EMU resulting from raising EVA pressure. The study presents the trade-off which optimizes the choice of reduced cabin pressure and increased EVA pressure.

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# ACKNOWLEDGEMENTS

Prebreathe Elimination Study considers many complex and diverse issues relevant to physiology, the Space Transportation System and payloads. To establish firm foundations for study conclusions, it is required that these issues be explored in detail and presented accurately and completely. Accordingly, the study method included establishing personal contacts in areas related to the issues and working with these people to develop the issues. Discussion memorandums were then prepared and cycled back through these contacts for review and comment. These discussion memorandums form the information base for the study and comprise the appendix to this report.

The author wishes to acknowledge input received, the many questions answered, issues clarified, and constructive comments and thoughtful reviews given by the following NASA JSC and contractor people:

- Jim Waligora and Dave Horrigan of SD3
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- Bobby Miller and Steve Truelock of NS2
- Ed Michel and Stan Luczkowski of SC
- Manuel Rodriguez and Sharon Lafuse of EC2
- Norm Prince of EC3
- Ed Whitsett of EC5
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- Jim Walischauer of Carleton Controls
- Bob Balinskas, Earl Bahl and Gordon Allen of Hamilton Standard

The contribution of an ILC-Dover subcontract to evaluate space suit joint performance at elevated pressure is also acknowledged.

R.C.W.
August, 1981

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# ECWS PREBREATHE ELIMINATION STUDY
# FINAL REPORT

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## INTRODUCTION

EVA planning for supporting STS flights calls for conducting EVA at 4.0 psia from a 14.7 psia cabin. To preclude "the bends", a painful and potentially dangerous physiological condition resulting from bubble formation when dissolved gasses in body tissues are driven out of solution by exposure to reduced ambient pressure during EVA, STS crewmembers prebreathe pure $O_2$ for 3 to 4 hours to purge body tissues of dissolved $N_2$, the prime constituent of bends bubbles. However, prebreathing has several drawbacks: the crew considers the Portable Oxygen System (POS) to restrict IVA prior to donning the EMU, and denitrogenation can be significantly reduced during EMU donning by inadvertently taking just one or two breaths of air, increasing likelihood of bends considerably unless specific (and cumbersome) procedures are followed rigorously.

Planning for OFT side-steps prebreathing by requiring reduction of cabin pressure to 9 psia for approximately 12 hours prior to EVA, which promotes sufficient washout of dissolved gasses from tissues to minimize likelihood of bends. This is not a permanent solution, because it does not address many Orbiter, payload, operational, and EVA issues relevant to operational STS flights. The objective of the Prebreathe Elimination Study is to define physiologically safe EVA and cabin pressure levels while achieving an acceptable compromise between conflicting Orbiter, payload, operational and EVA issues; all at an acceptably low technical risk. This study addresses issues of physiology, Pre-EVA procedures, payloads, Orbiter vehicle impacts and EMU impacts. The study also presents a trade study to select the optimum combination of reduced cabin pressure and increased EVA pressure, and identifies new technology areas to facilitate implementation.

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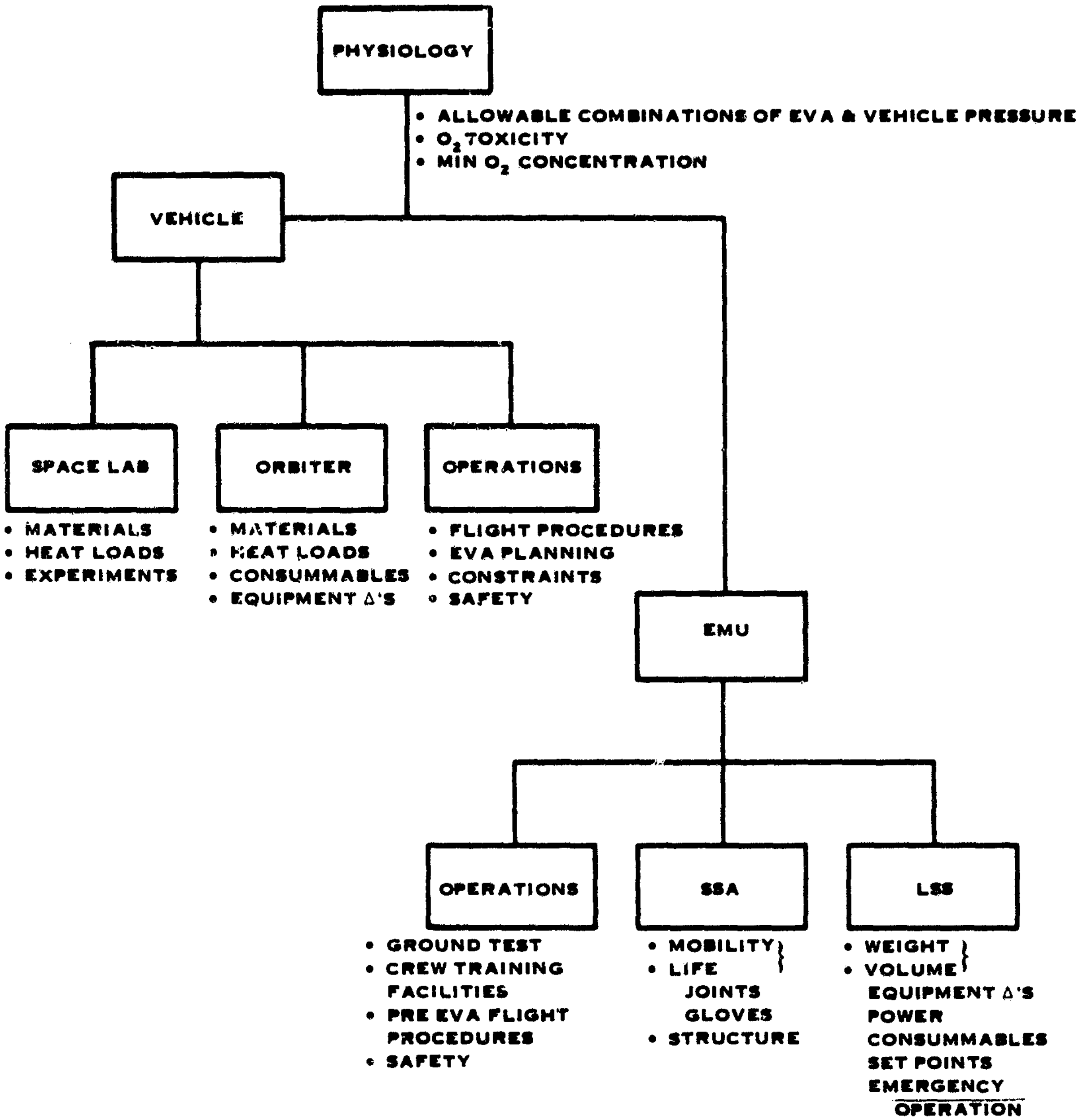
## PREBREATHE ELIMINATION STUDY ISSUES



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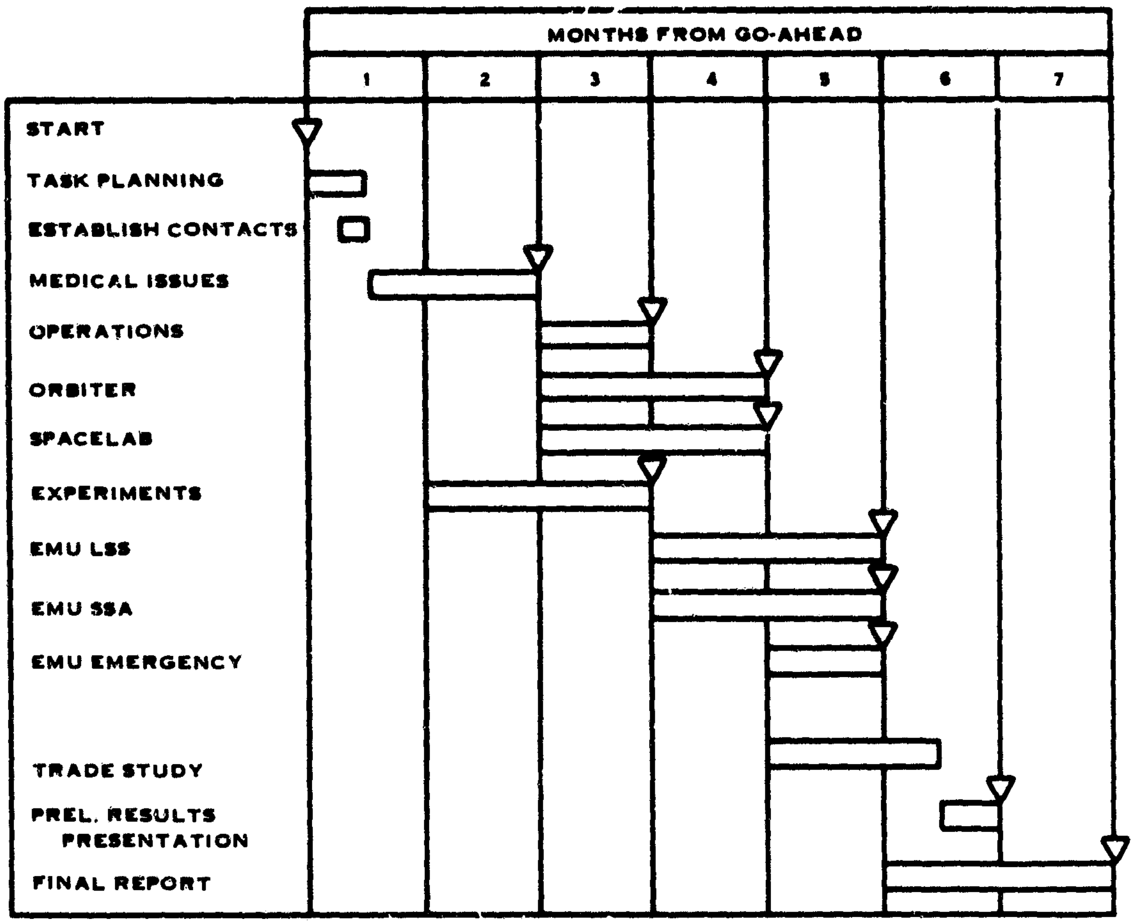
PREBREATHE ELIMINATION STUDY SCHEDULE



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## EXECUTIVE SUMMARY

### Summary of Major Conclusions

The executive summary highlights major study conclusions, summarizes issues affected by Orbiter cabin pressure, and lists impacts to EMU required to support EVA without prebreathe.

- The recommended optimum EVA pressure is 5.75 ± 0.1 psia.
- Recommended cabin pressure for operational flights with EVA is 11.8 ± 0.2 psia.
- The recommended combination of EVA and cabin pressure eliminates prebreathe prior to EVA. However, the crewmembers bodies must be in approximate equilibration with cabin $N_2$ levels prior to EVA. This requires a one-time denitrogenation, taking 1.1 hours on pure $O_2$, to support the first EVA within several hours of launch; or reducing cabin pressure to 11.8 psia for 12 hours prior to the first EVA. Subsequent EVA's can be performed without additional denitrogenation from an 11.8 psia cabin using existing EMU donning and checkout procedures verified for STS-1.
- The recommended cabin pressure meets existing maximum and minimum $O_2$ levels, based on hypoxia and materials considerations.
- The Orbiter vehicle requires automatic cabin pressure control at 11.8 psia. This requires adding one total pressure regulator and shut-off valve to each of two parallel cabin pressurization subsystems.
- Payload flight assignment planning should continue to avoid inclusion of experiments that are sensitive to subatmospheric cabin pressure to flights with either planned EVA or where backup EVA is a possibility.
- Approximately 82% of EMU components require no change to support EVA at 5.78 psia.
- Significant EMU modifications consist of new gloves, enlarged SOP, reworked suit joints, increased battery capacity and reset $O_2$ regulators. Minor modifications include revising flow restrictors, relief valves and C&W set points, and strengthening select structural elements.
- The accompanying chart shows cabin conditions approved for OFT only. Modification of the EMU will permit improving cabin conditions for operational flights.

# EMU CONFIGURATION
# IMPACT SUMMARY COMPARISON

| EMU Configuration | Present | No Prebreathe |
|---|---|---|
| Use | OFT w/o prebreathe | OPS Flights |
| Acceptable for OPS Flights | No | Yes |
| $P_{CABIN}$ - psia | $\boxed{9.0}$ | 11.8 |
| $P_{EVA}$ - psia | 4.1 | 5.78 |
| Minimum Cabin $PPO_2$ - psia | $\boxed{2.46}$ | 2.66 |
| Maximum Cabin % $O_2$ | $\boxed{30}$ | 25.9 |
| CABIN Pressure Control | $\boxed{\text{Manual}}$ | Automatic |
| Avionics Power Down - KW | ~4 | ~2 |
| EMU Mod's Required | No | Yes |

☐ Approved for OFT Only and not acceptable for operational flights

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## ALLOWABLE CABIN PRESSURE RANGE

Investigation of relevant study issues defines a window for locating the optimum reduced cabin pressure and increased EVA pressure. The window permits significant improvement in cabin conditions over those approved for OFT EVA support. Significant limits defining the window are shown on the accompanying chart.

### Physiology

When equilibrated with the cabin a crewmember may perform EVA without prebreathe, if EVA pressures are not less than those shown for corresponding cabin pressures.

Oxygen partial pressure must be above the 4,000 feet alveolar equivalent shown to avoid the first measureable effects of hypoxia, which is night blindness.

EVA pressure must be less than 6.0 psia nominal to avoid the requirement for hyperbaric chamber first aid treatment in case of explosive decompression during sea level manned testing.

### Avionics Cooling

Cabin pressure can be reduced to approximately 11.6 psia in a thermally benign environment without exceeding avionics temperatures defined by outlet air temperature specification limits, if the crew does not exceed four people and one of two GPC's in Avionics Bay 1 is powered down.

For more demanding thermal conditions both cabin fans can be run and some cabin electronics shutdown per Priority Powerdowns 1 through 3.

All load management results in maintaining sea level avionics box temperatures, thus incurring no degradation of performance or life.

### Payloads

Certain life science and carry-on experiments may be sensitive to subatmospheric cabin pressure. NASA should continue to screen experiments for pressure sensitivity, and those that are pressure sensitive should be assigned to flights without planned or backup payload support EVA.

### Materials

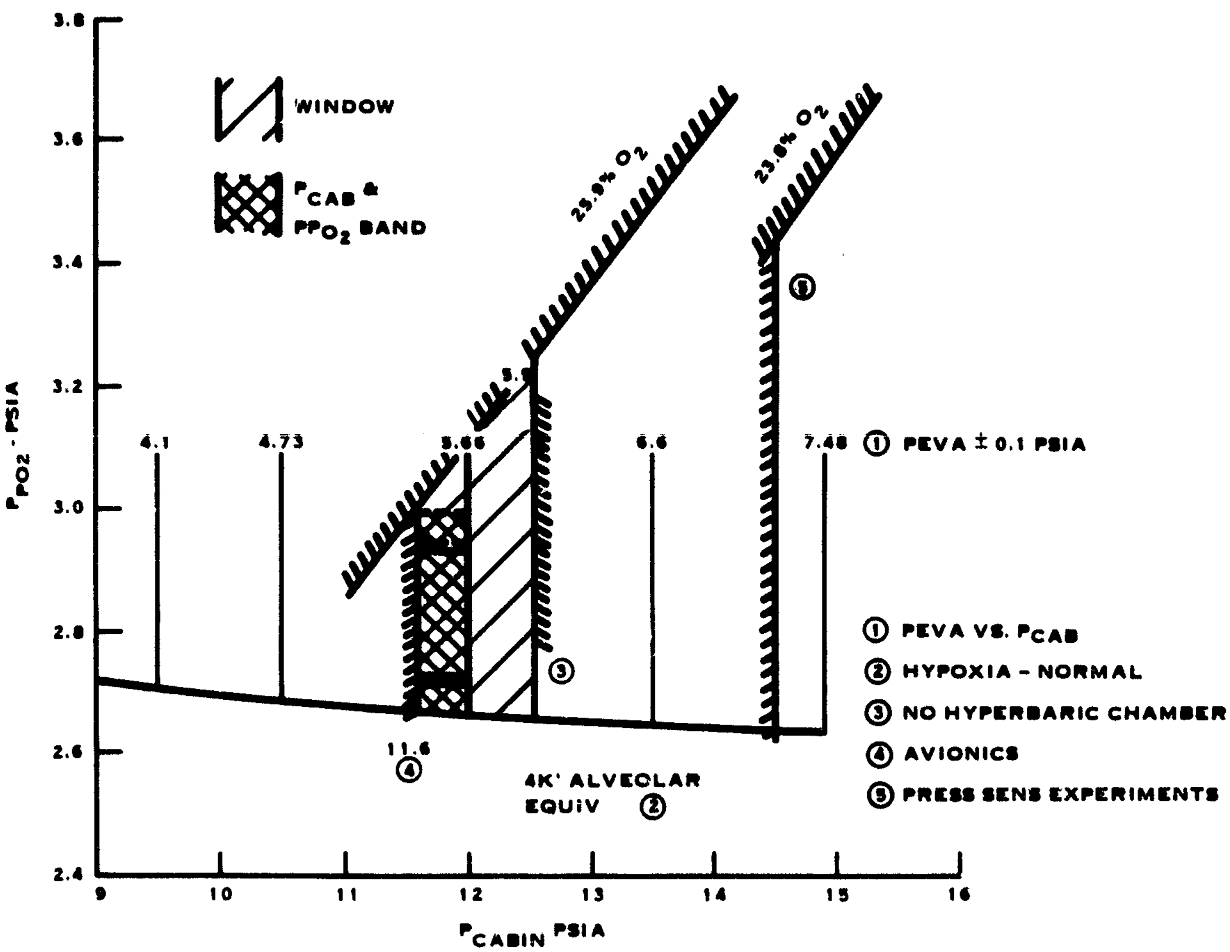
Present Orbiter cabin materials are rated for 25.9% maximum $O_2$ concentrations.

### Cabin Pressure Control

The new 1.5% $PPO_2$ sensor (which was installed in OV-102 just prior to STS-1), and the existing $O_2/N_2$ controller will support controlling $PPO_2$ to within a total band of 0.33 psi, including C&W and dead bands.

The existing total pressure regulator controls cabin pressure to within $\pm 0.2$ psia.

ALLOWABLE WINDOW




The above limits define the following window:

| | Minimum | Maximum |
|---|---|---|
| PCABIN Total ± 0.2 psia | 11.8 | 12.35 |
| $PPO_2$ - psia | 2.66 | 3.0 @ 11.6 psia |
| % | N/A | 25.9 |
| PEVA ± 0.1 psia | 5.66 | 5.9 |

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# EMU IMPACTS

The EMU consists of 22 CEI's comprising 117 components. Of these components only 21 require change (18%) to support EVA at 5.78 psia.

Significant changes are required to the items shown in the accompanying chart. These changes require evaluation to minimize their impact, and redesign requires development evaluation.

Minor changes are required in select areas. These are straightforward engineering modifications and do not require development evaluation.

Special test equipment at Hamilton Standard, ILC and JSC requires only minor modifications to support EVA at 5.78 psia. Changes include resetting relief valves in test rigs and interface adaptors and instrument recalibration. Handling fixtures may require modification, depending on extent of SOP change.

The United States Manned Space Program has developed a 4 psi EVA capability. The ( * ) items are new technology initiatives recommended to support implementation at 5.78 psia, to minimize hardware impacts, to assure understanding of issues and to verify procedures at the higher EVA pressure.

# EMU IMPACTS

No Change - 82% of EMU Components

Significant Changes -

- * SOP $O_2$ Capacity up 41%. May Impact:
  - AAP
  - Airlock Wall
  - MMU
- Battery Capacity up 8%
- * Joint Torque up 9 to 32%
- * New Glove Likely
- Modify $O_2$ Regulators

Minor Changes -

- Strengthen Select Structure
- Reset Select Flow Restrictors and Relief Valves
- Reset C&W Set Points

STE - Minor Changes Only

- * Integrated Testing Recommended

* New Technology

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## PHYSIOLOGY

A complete discussion of the physiology issues is contained in the appendix to this report. The issues were developed with cooperation from people at NASA JSC CB and SD3 and Brooks AFB SAM. The discussion is also based on previously published test data and position papers from CB and SD3, and reference material in the literature.

Physiological issues are grouped for presentation convenience into steady-state and transient limits. Steady-state limits are shown on the accompanying chart. Transient limits are discussed in the following six charts.

### Hypoxia

Hypoxia, or lack of oxygen, results when oxygen partial pressure in the lung falls below minimum threshold values. Symptoms become more pronouned as alveolar $O_2$ levels decline. The onset of hypoxia can be identified as a measureable decrease in night vision acuity. This threshold occurs at the 4,000 feet altitude equivalent. JSC SD3 sets this as the minimum $O_2$ partial pressure for normal STS activity on operational flights.

At 8,000 feet altitude alveolar equivalent the threshold of loss of ability to learn new tasks can be measured. SD3 sets this as the minimum $O_2$ partial pressure for emergency STS activity.

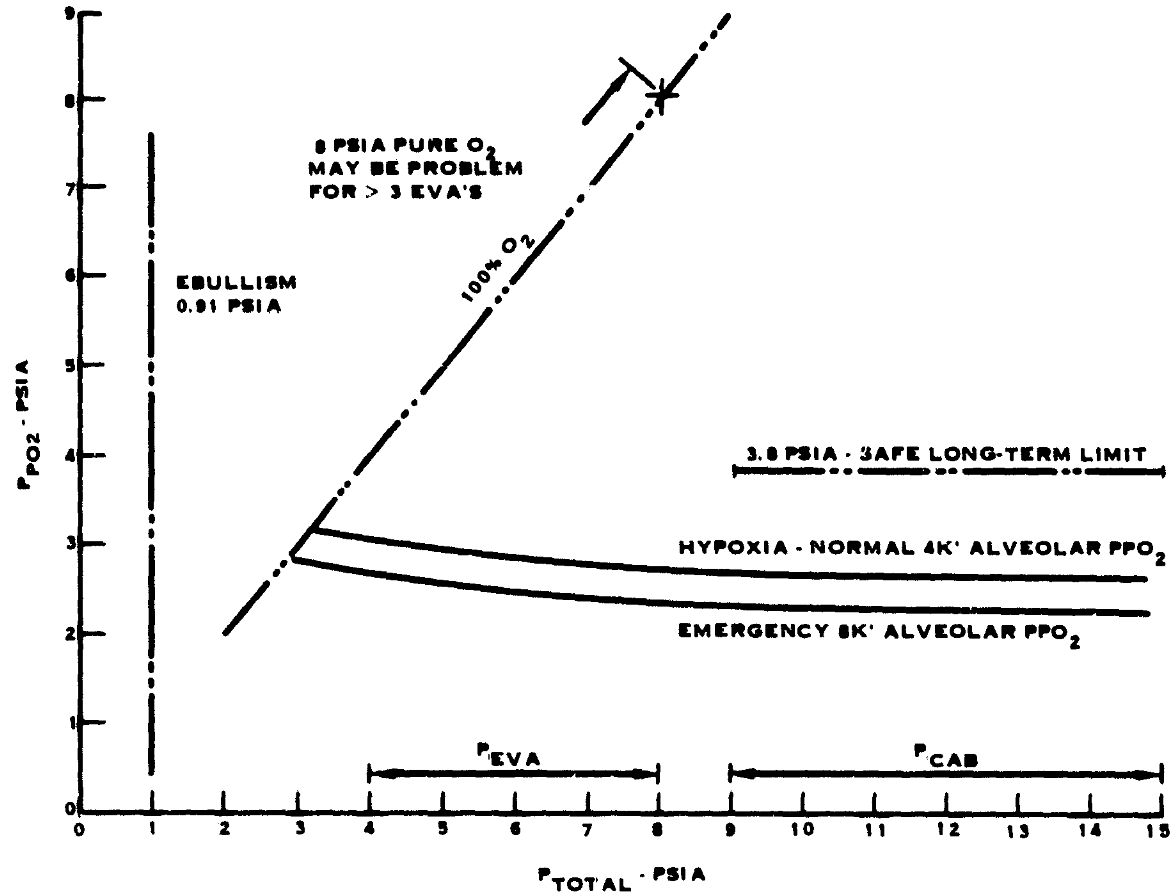
### Oxygen Toxicity

3.8 psia has been accepted as a safe, conservative, long term limit for cabin $O_2$ partial pressure based on hematology changes, which are the threshold effects of $O_2$ toxicity.

8.0 psia has been accepted as the maximum limit for EVA $O_2$ partial pressure for three EVA's from Shuttle. However, limited test data indicates that intermittent exposure to pure $O_2$ at 8 psi for more than three EVA's may be harmful. This would be of concern for EVA support from a space platform, but does not impact EVA from the Orbiter.

### Ebullism

0.91 psia is the vapor pressure of water at body temperature. Body fluid will boil if pressure surrounding the body falls below this level.




STEADY STATE PHYSIOLOGY LIMITS

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# TRANSIENT PHYSIOLOGICAL LIMITS

Transient limits define acceptable envelopes for limiting effects of explosive decompression and the "bends".

## Explosive Decompression

A sudden loss of suit integrity, such as loss of a glove or boot, would dump suit pressure in less than one second. If this occurs during sea level testing, some lung rupturing is a likely result at suit pressures over 6 psig. The rupture releases air into the pleural cavity, presenting an immediate danger of lung collapse and air embolism. A first aid treatment in controlling these effects is to repressurize the test subject in a hyperbaric facility at up to several atmospheres within several minutes of the mishap. NASA JSC safety policy requires rapid access to a hyperbaric facility at all sites where human testing in excess of 6 psig is conducted.

## Cause of the "Bends"

Body tissues contain dissolved gas in equilibrium with ambient pressure. When ambient pressure is reduced, bubbles form or expand from everpresent micronuclei. If the drop in pressure is not too great or too fast, bubbles evolve in the tissues and are carried in orderly fashion to the lungs by the bloodstream. The lungs act as gas separators, dumping evolved gas overboard.

Bends, or limb joint pain, can arise when the orderly evolution and transport of gas bubbles is impeded. "Bends" appears to be caused by gasses attempting to escape from poorly vascularized body tissues such as fat and scar tissue. Cold, stress, age and injuries, all of which inhibit micro circulation in these tissues, inhibit gas release and increase an individual's susceptability to bends. Individuals who release gas into the bloodstream as a bubble shower of sufficient intensity to mask the heart beat (as detected by doppler ultrasound) also appear to be bends-prone, developing symptoms in 15 to 20 minutes.

## Concern About "Bends"

Bends are of concern for three reasons. First, limb bends can be sufficiently painful to disable a crewmember, thus preventing one from taking other steps to help oneself. Second, a bubble shower of sufficient intensity can temporarily exceed the lungs capacity to degas the pulminary circulation completely, allowing bubbles to pass beyond the lungs into the "left side" circulation, where they may be pumped to other organs including the brain, causing severe and unpredictable reactions. Third, recent evidence suggests that blood platelets, which are responsible for starting the clotting process by detecting vascular injuries, may react to gas bubbles as though they were vascular injuries. Platelets disintegrate in the clotting process, releasing materials which both promote clotting, and enter into the clot itself. Tests indicate that bubbles breaking through blood vessel walls actually dislodge epethelial cells from the blood vessel walls. The concern is that bubbles could cause clotting, resulting in pulmonary thrombosis (blood clots in the lung) which is potentially very dangerous.

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## PHYSIOLOGICAL LIMITS - TRANSIENT

- Explosive Decompression

  > 6 psig Requires Hyperbaric Decompression

- "Bends" Limits

  - EVA Normal
  - $N_2$ Washout (Denitrogenation)
  - EVA Emergency

Transient Physiological Limits (Continued)

## Conservatism and Prediction

Bends susceptibility appears to be progressive within a given flight. An individual may experience some limb pain with the first decompression, but remain functional. Repressurization will relieve the pain. However, bubble micronuclei will remain in the tissues for up to 48 hours, causing more gas release during subsequent depressurizations. In the absence of a hyperbaric facility aboard the Oribiter it is necessary to eliminate bends during EVA by developing safe procedures for dissolved gas washout, establishing conservative R values (ratio of cabin $N_2$ pressure to EVA pressure), and ultimately to screen EVA candidates for bends tolerance.

Current USAF test experience shows that R values and gas washout equations cannot guarantee bends-free EVA for all individuals. R values are useful for identifying and evaluating candidate gas washout procedures. However, gas washout equations using a single $e^{-Kt}$ term model human tissues which are well perfused with blood vessels. In reality, the problem tissues are poorly vascularized and depend on gas diffusion through the tissues to the blood vessels, a process not well represented by these equations. Owing to variations between individuals in degree of vascularization of these tissues and in amounts of such tissues in the body, candidate gas washout procedures must be verified with human testing.

## Normal EVA Bends Limit

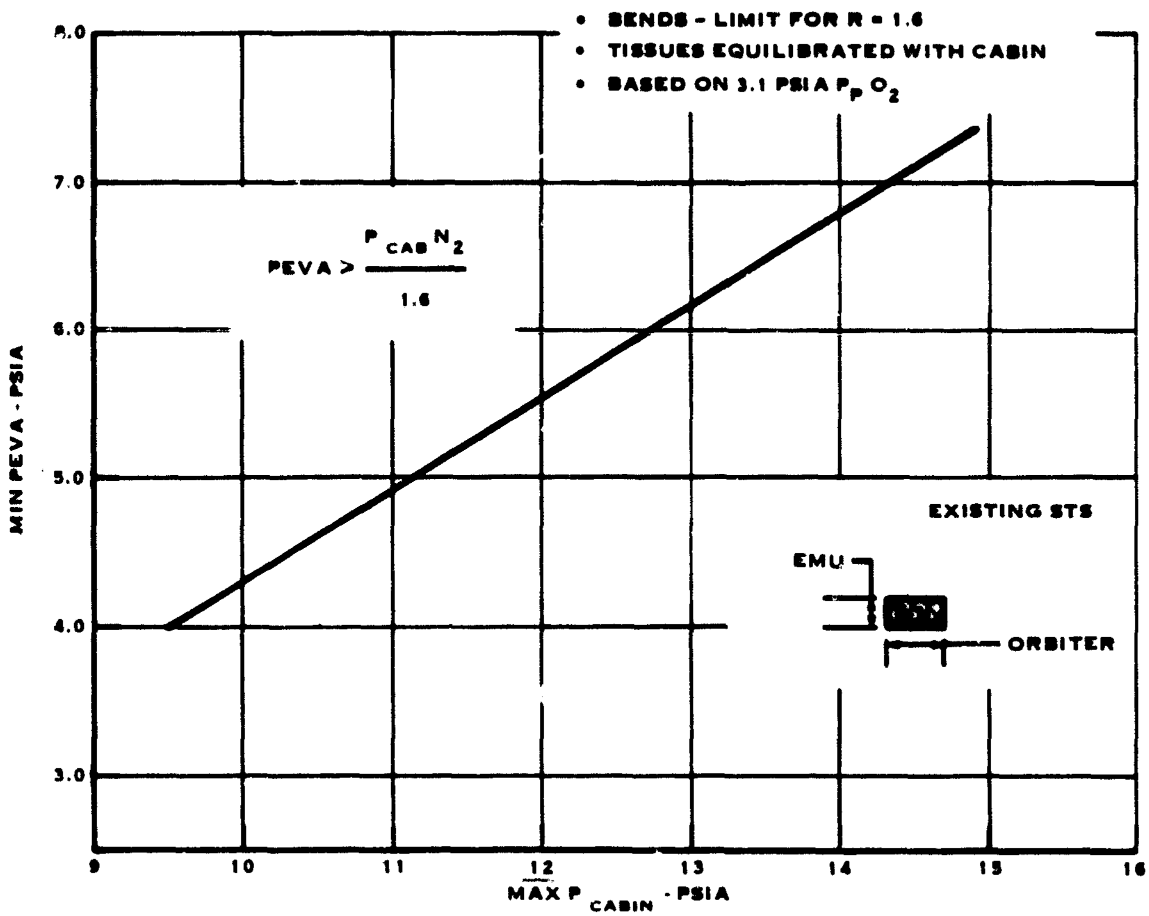
The accompanying chart shows the relationship between cabin pressure and EVA pressure at the accepted bends limit. The curve produces the same ratio between cabin $N_2$ level and EVA total pressure (1.6) as the standard USAF rapid decompression from sea level to 18,000 feet (1.58).

This curve is based on the assumption that the body is in equilibrium with the cabin $N_2$ level prior to EVA. The curve is from maximum cabin pressure to minimum EVA pressure. Applying tolerances defines the ranges of interest to be:

PCABIN = 9.3 to 14.7 $\pm$ 0.2 psia

PEVA = 4.1 to 7.4 $\pm$ 0.1 psia

## PEVA VS. $P_{CABIN}$ FOR NO PREBREATHE



# $N_2$ WASHOUT (DENITROGFNATION)

To perform $N_2$ washout calculations phiologists consider body tissues to have a "1/2 time", which is the time required to lose the one-half the dissolved $N_2$ in an exponential decay process. The body is considered to consist of three types of tissues:

- Fast - Half time is 180 minutes
- Intermediate - Half time is 240 minutes
- Slow - Half time is 360 minutes

Experience has shown that washout procedures produce an acceptably low incidence of bends (less than 5%) if the tissue dissolved gas (PTDG) level resulting from the procedure is less than or equal to the following ratios with respect to EVA total pressure:

- $PTDG_{240} = 1.6 \times PEVA$ (Intermediate tissues)
- $PTDG_{360} = 1.8 \times PEVA$ (Slow tissues)

Evaluating tissues dissolved gas levels resulting from breathing a mixture of cabin $O_2/N_2$ follows the following exponential decay equations:

$$PTDG = PI_0N_2 \pm (PIN_2 - PI_0N_2)\,(1-e^{-kt})$$

where: $PI_0N_2$ is the inspired $N_2$ level to which the body tissues are initially equilibrated.

$PIN_2$ is the inspired $N_2$ level at reduced cabin pressure.

k is a constant which includes tissue one-half time.

When breathing pure $O_2$ the $PIN_2$ term goes to zero, causing the equation to simplify to:

$$PTDG = PI_0N_2 - (PI_0N_2)\,(e^{-kt})$$

## DENITROGENATION

- 3-Tissue Model

- 360 Minute 1/2 Time "SLOW" Tissues

  240 Minute 1/2 Time "INTERMEDIATE" Tissues

- Washout Procedures OK if...

  $PTDG_{360} \leq 1.8 \times PEVA$

  $PTDG_{240} \leq 1.6 \times PEVA$

- Breathing Cabin Gas

  $PTDG = PI_oN_2 \pm (PIN_2 - PI_oN_2)\ (1-e^{-kt})$

- Breathing Pure $O_2$

  $PTDG = PI_oN_2 - (PI_oN_2)\ (e^{-kt})$

## $N_2$ WASHOUT CURVES

The accompanying chart is a plot of the two denitrogenation equations at four cabin pressures selected for this study for the slow and intermediate tissues. The curves are based on breathing cabin gas at the 4,000 feet altitude alveolar equivalent which yields the highest $PIN_2$ and hence the slowest $N_2$ washout. The carats (◁) in the right hand margin represent $PIN_2$ at each cabin pressure. Tissues become equilibrated with inspired $N_2$ at t = infinity.

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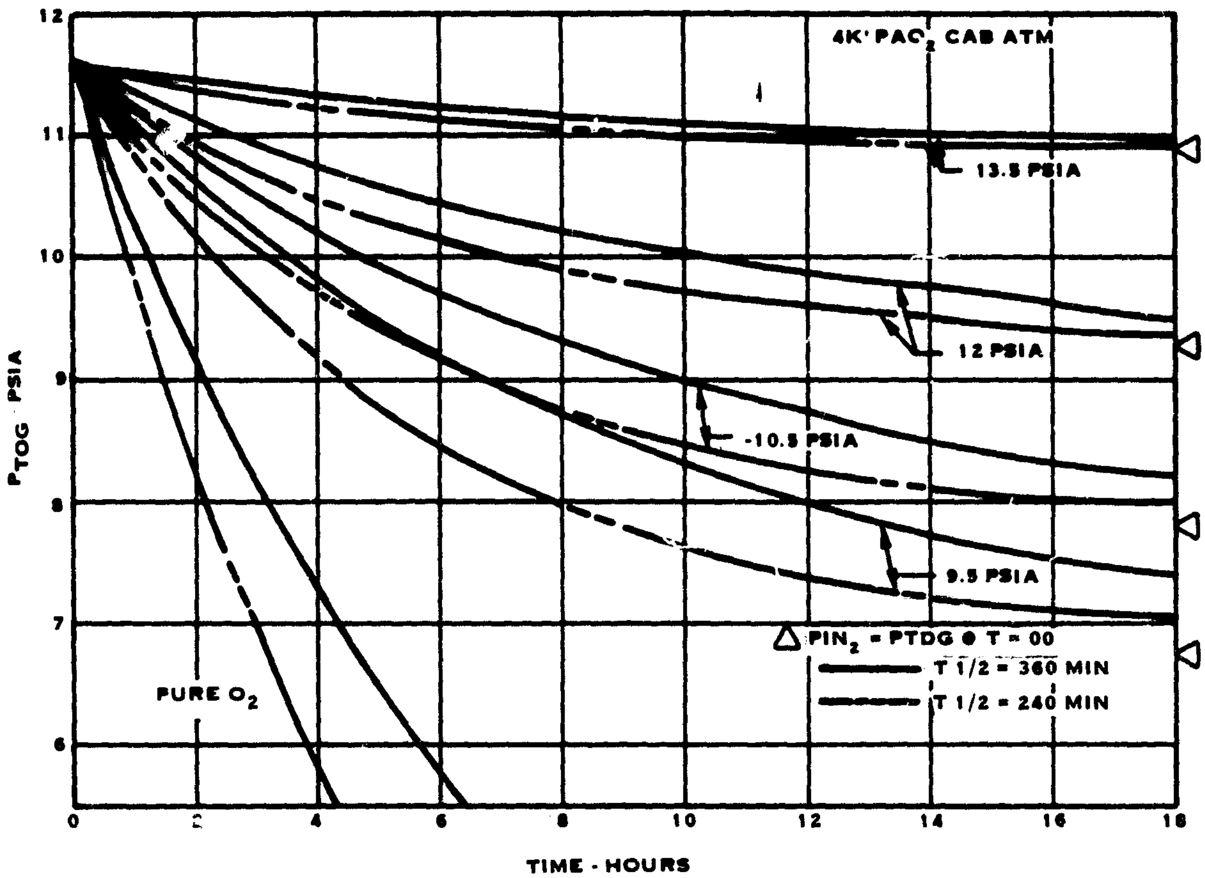
## TISSUE DISSOLVED GAS LEVEL AFTER WASHOUT WITH CABIN GAS



## NEED FOR INITIAL DENITROGENATION

The accompanying chart shows the need for a one-time denitrogenation to bring body tissues close to equilibrium with reduced cabin $N_2$ pressure levels. The chart shows that breathing cabin gas alone will not produce low enough tissue dissolved gas levels to support EVA at PTDG/1.6 levels.

The major problem is that the denitrogenation equation expresses an exponential decay. The intended washout uses the differential between PTDG and $PIN_2$ to drive PTDG toward $PIN_2$. However, PTDG will never reach $PIN_2$ because the driving force approaches zero as the differential approaches zero.

The second problem is that the cabin is $N_2$ rich, resulting from using $PPO_2$ at the 4,000 feet altitude alveolar level.

Solving the first problem requires driving PTDG down to $PIN_2$ prior to the first EVA, and doing it quickly to support mission objectives. Tissues will renitrogenate to $PIN_2$ levels after the first EVA, but will not exceed these levels. Thus the washout is a one-time requirement, and will not be required for subsequent EVA's. The next section of this report considers three candidate Pre-EVA procedures for achieving this initial dissolved gas washout.

The second problem is solved by retaining the STS-1 EVA pre-egress procedure of checking out the EMU in the airlock after donning while breathing pure $O_2$ from the SCU for 20 minutes. This appears sufficient to offset the effect of the $N_2$-rich cabin, and is included in all three candidate Pre-EVA procedures.

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## NEED FOR ONE-TIME DENITROGENATION

| MAX. PCAB (PSIA) | MAX. $PIN_2$ (1) (PSIA) | MIN. PEVA (PSIA) | MAX. PTDG (2) (PSIA) | TIME (HOURS) |
|---|---|---|---|---|
| 14.7 | 11.60 | 7.25 | 11.60 | 0 |
| 13.5 | 10.88 | 6.50 | 10.40 | NEVER |
| 12.0 | 9.34 | 5.56 | 8.90 | NEVER |
| 10.5 | 7.81 | 4.63 | 7.40 | NEVER |
| 9.5 | 6.79 | 4.00 | 6.40 | NEVER |

(1) Minimum $O_2$ 4K' $PPO_2$ Alveolar equivalent = PTDG @ $T = \infty$

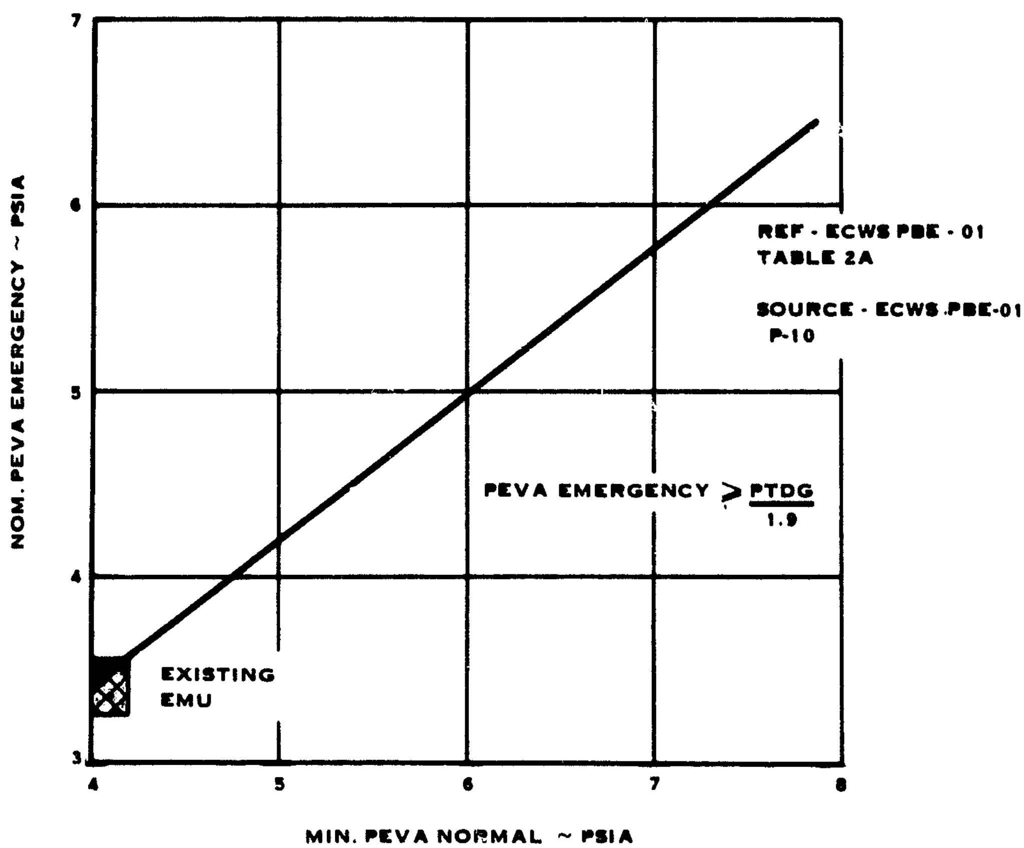
(2) 1.6 x PEVA

## EVA EMERGENCY

Initial EMU planning calls for 3 to 4 hours of pure $O_2$ prebreathing to protect against decompression effects in going from a 14.7 psia cabin to 4.1 psia EVA pressure. This results in an R value of approximately 1.6 in the 240 minute tissues. The EMU SOP will maintain pressure at 3.35 psia, resulting in a 240 minute R value of approximately 1.9. If an emergency extends beyond 15 to 20 minutes, the risk of experiencing bends exists.

Use of the SOP at higher EVA pressures should not entail higher risk than the present EMU. Accordingly, the accompanying chart shows the relationship between normal and emergency EVA pressures to retain $P_{EVA}$ emergency $\geq$ PTDG/1.9.

## PEVA EMERGENCY FOR R $\leq$ 1.9 FOLLOWING 24 HRS AT REDUCED $P_{CAB}$ W/O PREBREATHE



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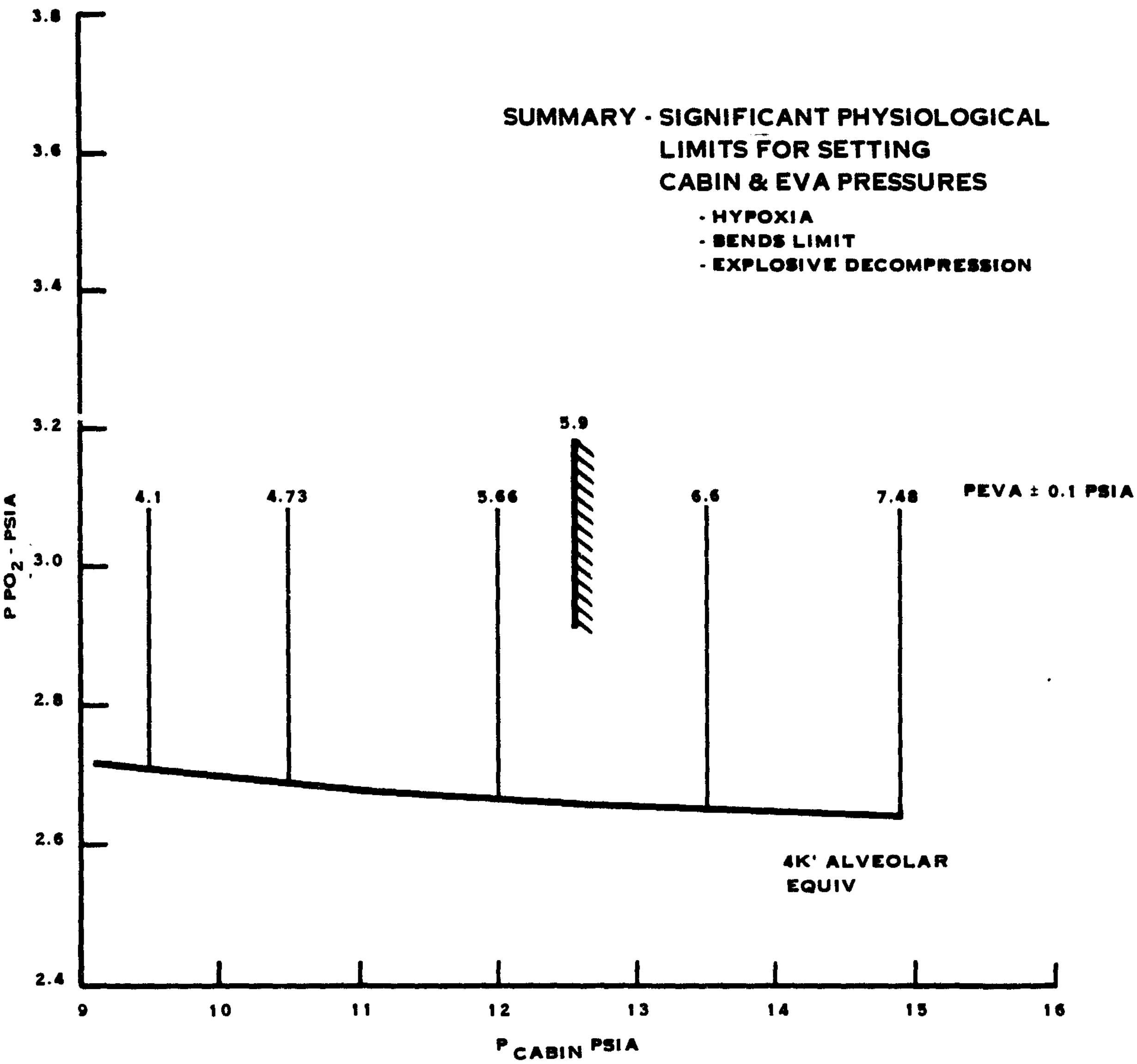
## SIGNIFICANT PHYSIOLOGICAL LIMITS

The accompanying chart shows the three physiological limits that are significant in setting cabin and EVA pressure levels. They are:

| | |
|---|---|
| - Hypoxia Limit | 4,000 feet altitude equivalent alveolar $PPO_2$ for normal STS operations. |
| - Bends Limit | PEVA is greater than or equal to the sea level cabin $N_2$ level/1.6 as shown by the ticks of EVA pressure at given cabin pressure values. |
| - Explosive Decompression | 6.0 psig (nominal) for sea level manned testing. |

This curve format will be used to summarize significant limits developed in subsequent sections of this report in order to define the window of acceptable operating conditions.


SUMMARY - SIGNIFICANT PHYSIOLOGICAL
LIMITS FOR SETTING
CABIN & EVA PRESSURES
- HYPOXIA
- BENDS LIMIT
- EXPLOSIVE DECOMPRESSION
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
P PO2 - PSIA
5.9
4.1
4.73
5.66
6.6
7.48
PEVA ± 0.1 PSIA
4K' ALVEOLAR
EQUIV
9
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12
13
14
15
16
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## PRE-EVA PROCEDURES

A complete discussion of EVA procedure issues is contained in the appendix to this report. These issues were developed with cooperation from people at NASA JSC SD3, CB and CG3. This section considers candidate procedures for achieving initial tissue dissolved gas washout. R values are useful for evaluating candidate procedures. Recent USAF human testing has verified that some washout procedures are safe, i.e., incur acceptably low incidence of bends. Analysis of these procedures shows resulting R values of approximately 1.8 in 360 minute tissues and between 1.45 and 1.58 in 240 minute tissues. Hence, this study considers candidate tissue dissolved gas washout procedures to be viable if they produce maximum R values of 1.8 in 360 minute tissues and 1.6 in 240 minute tissues. All these procedures address initial reduction of PTDG to support EVA at a factor of 1.6 below sea level $PIN_2$.

R values are used only to define and evaluate candidate washout procedures. Viable candidate procedures should be verified by human testing before they become operational. Human testing is necessary, because individuals vary widely in their susceptibility to bends, owing to such factors as age, physical condition, amount of body fat, and presence of scar tissue. In addition, temperature, activity level, and time since last decompression affect a particular individual's susceptibility to bends. Moreover, published literature indicates that women may be more bends-prone than men.

Three candidate tissue dissolved gas washout procedures are presented which appear to be safe for supporting EVA. All procedures accelerate tissue dissolved gas washout towards equilibrium with the cabin, so that the suit can be donned with crewmembers breathing just cabin atmosphere. These procedures eliminate requirements to breathe pure $O_2$ during donning, thus significantly simplifying suit donning. The three procedure candidates differ from one another in time to first EVA.

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## PRE-EVA PROCEDURES

- Eliminate POS Use During EMU Donning (Significant Safety and Operational Problem with Prebreathe)
- Based on FOD Input and STS EVA Planning
- Use Physiological Limits Evaluation
- Consist of...
    - Three procedures for one-time $N_2$
    - Washout for "Launch Day" and "Next Day" EVA's
    - Intermediate airlock pressure for significant prebreathe reduction

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## "LAUNCH DAY" PROCEDURE

The purpose of the "launch day" procedure is to washout tissue dissolved gas quickly so that EVA can be performed shortly after orbit insertion. The procedure calls first for breathing pure $O_2$ for a prescribed time to drive tissue dissolved gas level from sea level toward cabin inspired $N_2$ levels, the prescribed time being a function of cabin pressure on-orbit. The cabin pressure is reduced to on-orbit level during this time. Next, the crewmember breathes cabin gas for one hour while completing Pre-EVA activity, preparing EVA equipment, entering the airlock, and donning the suit. The last step is to purge the suit with pure $O_2$ using the OPA, spending approximately 20 minutes while checking out the suit prior to dumping the airlock to vacuum. These steps and durations are consistent with STS-1 EVA operations planning.

The procedure can be performed two ways, depending on how soon EVA is planned after initial orbit insertion. If EVA is to occur almost immediately, crewmembers can begin washout during prelaunch and launch using the Launch-Entry Helmet (LEH). If EVA is planned for later in "launch day", crewmembers can start washout after post-orbit insertion tasks are complete, using the Portable Oxygen System (POS).

The POS is flight-ready to support tissue dissolved gas washout. The LEH is expected to require modification for closed loop operation. At present, the LEH operates open loop to support launch and entry, but could cause excessive cabin $O_2$ enrichment if used by both pilot and mission specialist for washout, especially at low cabin pressure. Bulkiness of $O_2$ hoses, required for closed loop operation, could encumber the pilot.

The accompanying chart contains an analysis of "launch day" EVA procedures in terms of resulting R values for 360 and 240 minute tissues. The table shows the following:

- Washout durations range from zero to 3.7 hours, depending upon on-orbit cabin pressure and associated EVA pressure.
- No pure $O_2$ washout is required prior to donning for sea level cabin pressure to support EVA down to 7.25 psia. Twenty minutes in pure $O_2$ prior to dumping the airlock to vacuum appears to provide adequate margin to accommodate a slightly $N_2$-rich atmosphere which could result from controlling $PPO_2$ to the minimum (4,000 feet alveolar equivalent).
- 240 minute tissues (R  1.6) set washout duration requirements down to cabin pressures of 12 psia.
- 360 minute tissues (R  1.8) set washout duration at cabin pressures between 10.5 and 9.5 psia.

It should be noted that body fast tissues will renitrogenate quickly to $PIN_2$ levels of the reduced pressure cabin during suit donning. For this reason whole body gas washout will not be as complete as if pure $O_2$ were breathed continuously up to suit purge. The 9 and 10.5 psia cases reflect this for 240 minute tissues for which R is approximately 1.60. Without renitrogenation, R would be approximately 1.56 and 1.36, respectively.

# LAUNCH DAY TISSUE DISSOLVED GAS WASHOUT PROCEDURE

Procedure consists of:

- Washout with pure $O_2$ for prescribed duration while reducing PCab to on-orbit level.
- Breathe cabin atmosphere for one hour. Perform EVA equipment preparation and suit donning.
- Purge suit with pure $O_2$ and spend 20 minutes performing EVA checkout prior to dumping the airlock to vacuum.

| Max. PCab psia | 4k' Equiv. $PPO_2$ | Min. PEVA psia | Pure $O_2$ Washout time, hours | Resulting R Values 360 Min. $R = \frac{PTDG}{PEVA}$ | 240 Min. $R = \frac{PTDG}{PEVA}$ |
|---|---|---|---|---|---|
| 14.7 | 2.63 | 7.25 | 0 | 1.60 | 1.57 |
| 13.5 | 2.64 | 6.5 | 0.3 | 1.65 | 1.60 |
| 12.0 | 2.66 | 5.56 | 1.2 | 1.73 | 1.60 |
| 10.5 | 2.69 | 4.63 | 2.4 | 1.80 | 1.59 |
| 9.5 | 2.71 | 4.0 | 3.7 | 1.80 | 1.60 |

"NEXT DAY" PROCEDURES

The purpose of the two "next day" procedures is to assist tissue dissolved gas washout by breathing cabin gas at reduced pressure. This minimizes the requirement to use any pre-donning equipment. The procedure calls for reducing cabin pressure shortly after orbit insertion. The crew then eats, sleeps, and performs normal IV tasks until the next day. Following EVA equipment preparation and suit donning, the EVA crewmember purges the suit with pure $O_2$ and spends approximately 20 minutes performing EVA checkout prior to dumping the airlock to vacuum.

The procedure can be performed two ways, depending on how soon EVA is planned after reducing cabin pressure. The first approach is to reduce cabin pressure approximately 24 hours prior to EVA. The second approach is to shorten that time to 12 hours, which is consistent with STS-1 mission planning, followed by a brief washout using pure $O_2$ (up to one-half hour) to accelerate equilibration of body tissues with the cabin atmosphere.

The accompanying chart shows an analysis of the "next day" procedure performed after 24 hours at reduced cabin pressure. The table shows resulting R values calculated for 360 and 240 minute tissues. As expected, the chart shows resulting R's for all cabin pressures which are significantly below limiting values of 1.8 for 360 minute tissues. However, resulting R's for 240 minute tissues slightly exceed 1.6 for cabin pressures below 10.5 psia. JSC Medical's position is that these resulting R's are expected to be acceptable, pending verification by manned testing. This procedure eliminates all requirements for tissue dissolved gas washout using pure $O_2$ prior to suit donning.

# NEXT DAY TISSUE DISSOLVED GAS WASHOUT PROCEDURE
## (24 HOURS PRIOR TO EVA)

Procedure consists of:

- Reduce cabin pressure for 24 hours prior to EVA checkout.
- Breathe cabin gas for 24 hours. Complete EVA preparation and suit donning.
- Purge suit with pure $O_2$ and spend 20 minutes performing EVA checkout prior to dumping the airlock to vacuum.

| Max. PCab | 4k' Equiv. $PPO_2$ | Min. PEVA | Cabin Depressurization Duration | Resulting R Values 360 Min. $R = \frac{PTDG}{PEVA}$ | 240 Min. $R = \frac{PTDG}{PEVA}$ |
|---|---|---|---|---|---|
| psia | | psia | hours | | |
| 14.7 | 2.63 | 7.25 | 24 | 1.60 | 1.57 |
| 13.5 | 2.64 | 6.5 | 24 | 1.62 | 1.58 |
| 12.0 | 2.66 | 5.56 | 24 | 1.64 | 1.59 |
| 10.5 | 2.69 | 4.63 | 24 | 1.67 | 1.60 |
| 9.5 | 2.72 | 4.0 | 24 | 1.71 | 1.62 |

"NEXT DAY" PROCEDURES (Continued)

The accompanying chart shows analysis of an alternative "next day" procedure which uses 12 hours of reduced cabin pressure prior to suit purge. The chart shows the following:

- A short tissue dissolved gas washout prior to suit donning using pure $O_2$ is required for cabin pressures below 13.5 psia to support bends-limit EVA. Washout durations using pure $O_2$ range up to 0.5 hours, depending on cabin pressures and associated EVA pressure.

- Zero duration is required to support bends-limit EVA from cabin pressures down to 13.5 psia. Spending 20 minutes in pure $O_2$ during EVA checkout appears to provide adequate protection.

- 240 minute tissues ($R \leq 1.6$) set duration of pure $O_2$ purge prior to suit donning for cabin pressures below 14.7 psia. Resulting R's for 360 minute tissues are all well below the 1.8 limit.

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NEXT DAY TISSUE DISSOLVED GAS WASHOUT PROCEDURE
(12 HOURS PRIOR TO EVA)

Procedure consists of:

- Reduce cabin pressure for 12 hours prior to EVA checkout.
- Breathe pure $O_2$ for minimum duration to accelerate equilibration of body tissues with reduced pressure cabin atmosphere.
- Breathe cabin gas for one hour duration. Perform EVA preparation and suit donning.
- Purge suit with pure $O_2$ and spend 20 minutes performing EVA checkout prior to dumping the airlock to vacuum.

| Max. PCab | Min. PEVA | Cabin Depressurization Duration | Pure $O_2$ Washout Duration | Resulting R Values 360 Min. $R = \frac{PTDG}{PEVA}$ | 240 Min. $R = \frac{PTDG}{PEVA}$ |
|---|---|---|---|---|---|
| psia | psia | hours | hours | | |
| 14.7 | 7.25 | 12 | 0 | 1.60 | 1.57 |
| 13.5 | 6.5 | 12 | 0.2 | 1.64 | 1.59 |
| 12.0 | 5.56 | 12 | 0.2 | 1.66 | 1.59 |
| 10.5 | 4.63 | 12 | 0.3 | 1.74 | 1.59 |
| 9.5 | 4.0 | 12 | 0.5 | 1.78 | 1.60 |

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## INTERMEDIATE AIRLOCK PRESSURE

The study also includes the possibility that it may be disadvantageous for equipment or Orbiter reasons to adjust EVA and/or cabin pressures sufficiently to eliminate prebreathe altogether. A potential work-around consists of setting the airlock at an intermediate pressure from which it would be safe to perform EVA, and to prebreathe before entering the airlock.

Prebreathe would be terminated within the airlock prior to donning the suit. This work-around allows breathing the airlock atmosphere during suit donning and eliminates use of the POS and breather hose/mouthpiece during donning. Relieving this requirement would simplify EMU donning significantly.

The procedure for using intermediate airlock pressure starts with prebreathing for a prescribed duration, depending on cabin pressure and EVA pressure, as shown in the accompanying chart; then completing EVA equipment preparation before terminating prebreathe, entering the airlock and closing the inner hatch.

The intermediate airlock total pressure requires $N_2$ partial pressure to be 1.6 times PEVA plus a minimum $O_2$ partial pressure equivalent to 4k' alveolar. Thus the airlock pressure to support 4 psia EVA has 6.4 psi $N_2$ plus 2.7 psi $O_2$ for a total of 9.1 psia. To achieve this, the airlock is depressurized briefly to 7.8 psia, followed by repressurization with pure $O_2$. Four psi EVA requires the greatest amount of $O_2$ to repressurize the airlock, hence results in the highest $O_2$ percentage in the airlock.

Once the intermediate airlock pressure is achieved, terminate prebreathe. Don the pressure garment assembly while breathing the airlock atmosphere. Then purge the suit with pure $O_2$ and perform EVA checkout for approximately 20 minutes prior to dumping the airlock to vacuum.

The accompanying chart shows prebreathe times and resulting R values for all cabin and EVA pressures considered in this study, as well as airlock intermediate pressures and $O_2$ percentages. As expected, prebreathe times range from 0 to 3.8 hours depending on the selected combination of cabin and EVA pressure. At the lowest EVA pressure, 360 minute tissues determine prebreathe time. At higher EVA pressures the 240 minute tissues determine prebreathe time. The chart also shows that using reduced $N_2$ pressure in the airlock would allow significant reduction in prebreathe times if cabin pressure is lowered several psi or if EVA pressure is raised from one to two psi.

# INTERMEDIATE AIRLOCK PRESSURE

Procedure consists of:

- Establish orbital cabin pressure level.
- To support "launch day" EVA prebreathe pure $O_2$ based on 14.7 psi cabin. For "next day" EVA breathe cabin atmosphere for 12 hours, then prebreathe pure $O_2$ based on on-orbit cabin pressure.
- Complete EVA preparation, enter airlock, and set airlock intermediate pressure ($PPN_2$ = 1.5 PEVA, $PPO_2$ = 4k' alveolar).
- Terminate prebreathe; don suit.
- Purge suit with pure $O_2$ and spend 20 minutes performing EVA checkout prior to dumping the airlock to vacuum.

## INTERMEDIATE AIRLOCK PRESSURE

| MIN. PEVA (PSIA) | A/L $PN_2$ (PSIA) | A/L $PO_2$ (PSIA) | A/L PTOT (PSIA) | A/L $FIO_2$ (%) | MAX $P_{CAB}$ (PSIA) | PREBREATHE TIME (HOURS) | RESULTING R PTDG/PEVA (240 MIN) | RESULTING R PTDG/PEVA (360 MIN) |
|---|---|---|---|---|---|---|---|---|
| 4.0 | 6.4 | 2.7 | 9.1 | 30 | 9.5 | 0.6 | 1.58 | 1.80 |
| | | | | | 10.5 | 1.4 | 1.53 | 1.80 |
| | | | | | 12.0 | 2.5 | 1.51 | 1.80 |
| | | | | | 13.5 | 3.4 | 1.51 | 1.80 |
| | | | | | 14.7 | 3.8 | 1.51 | 1.80 |
| 4.63 | 7.1 | 2.7 | 9.8 | 28 | 9.5 | 0 | 1.51 | 1.66 |
| | | | | | 10.5 | 0.3 | 1.59 | 1.54 |
| | | | | | 12.0 | 1.2 | 1.51 | 1.80 |
| | | | | | 13.5 | 2.1 | 1.57 | 1.80 |
| | | | | | 14.7 | 2.5 | 1.54 | 1.80 |
| 5.56 | 8.9 | 2.7 | 11.6 | 23 | 10.5 | 0 | 1.51 | 1.54 |
| | | | | | 12.0 | 0.1 | 1.60 | 1.71 |
| | | | | | 13.5 | 0.9 | 1.60 | 1.72 |
| | | | | | 14.7 | 1.3 | 1.59 | 1.74 |
| 6.5 | 10.4 | 2.7 | 13.1 | 21 | 13.5 | 0 | 1.58 | 1.64 |
| | | | | | 14.7 | 0.3 | 1.60 | 1.65 |

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## PAYLOADS

A complete discussion of payload issues is contained in the appendix to this report. The issues were developed with cooperation from people from NASA JSC EA8, PF, NS2 and SC. The discussion is also based on current NASA flight assignment planning. Although flight assignment plans change constantly, they serve to identify issues and suggest solutions to problems.

Payload Sensitivity to Low Cabin Pressures - Economical delivery of payloads to orbit is the reason for STS's existence. Some payloads exposed to cabin pressure are pressure sensitive. Information return from these could be impaired by reducing cabin pressure to support EVA. All payloads exposed to cabin pressure must use materials rated acceptable for exposure to $O_2$ concentrations up to 25.9%. Payloads exposed to higher $O_2$ concentrations may have material incompatibility problems.

Payloads may be classified into three broad categories: satellites, structures, and experiments.

- Satellites - Satellites will be delivered to low earth orbit by STS. Satellites are carried in the Orbiter payload bay, and are not sensitive to cabin pressure.

- Structures - No structure payloads have been booked to date for delivery to orbit, but structure concepts are being developed. Structures are expected to consist of several or many individual payloads. Structure payloads are not expected to be sensitive to cabin pressure.

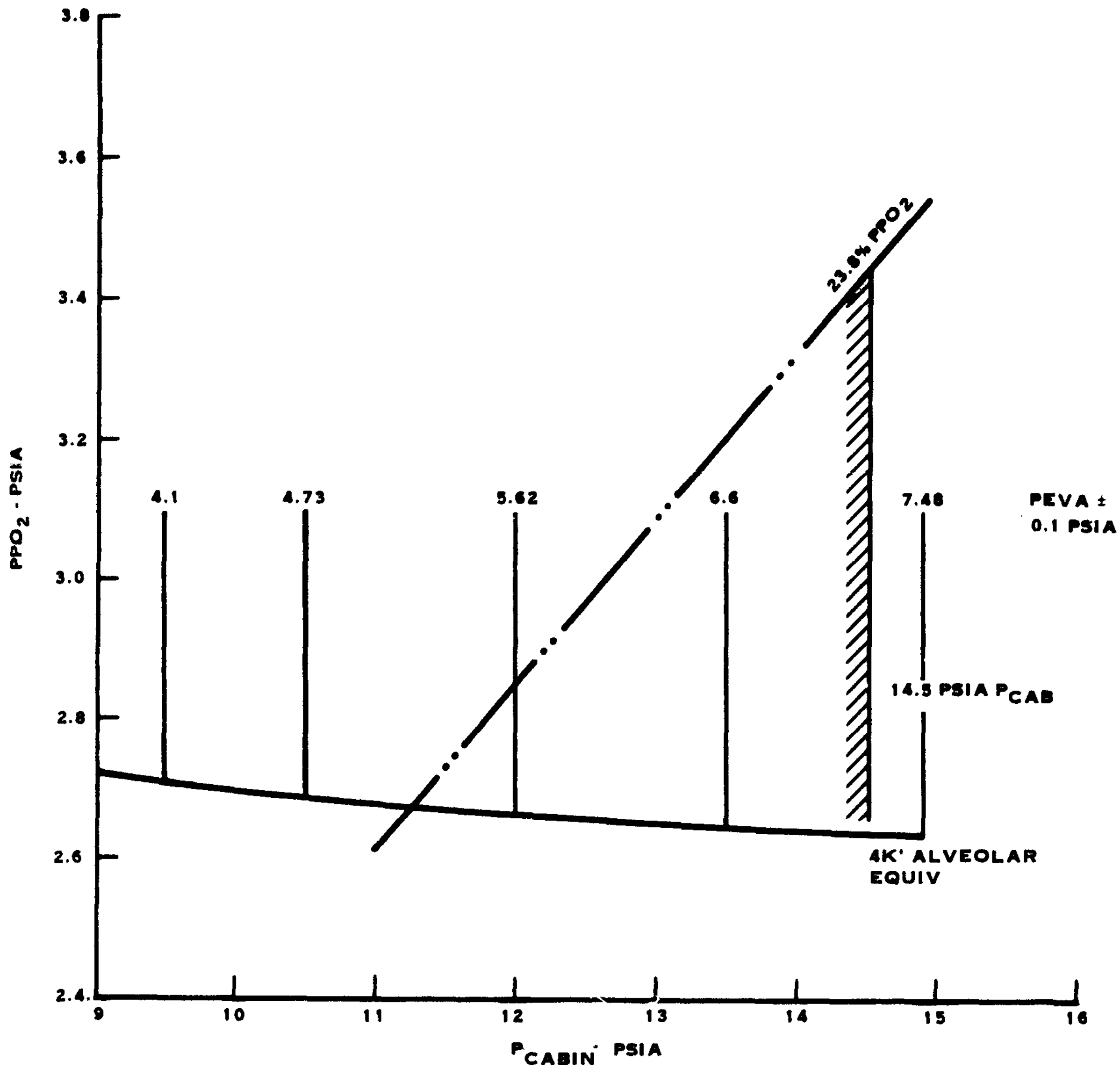
- Experiments - Experiments are assigned to payloads which remain with the Orbiter while in orbit. Experiments will be carried externally and internally. Internal experiments will be carried both in Spacelab modules and in the cabin, hence will be exposed to cabin atmosphere. Some of these may be pressure sensitive.

  The NASA JSC Life Sciences Directorate considers many life science experiments, as exemplified by cardio-pulmonary experiments, to be pressure sensitive. Even the variation from sea level (14.7 psia) to 5,000 feet at Denver (12.5 psia) may be significant. Experiments involving hematology are sensitive to $O_2$ concentration. Control experiments in both areas are being run at sea level because Spacelab and Orbiter have been designed to provide a sea-level atmosphere, and compensation for altitude effects may require more than simple gas law corrections. Thus, reducing cabin pressure could alter information obtained from an experiment and may reduce the value of control experiments run at sea level.

Life science experiments may be carried aboard any and all Spacelab module flights, even though the primary missions for these flights are for purposes other than life sciences. In addition, cooling provisions for Spacelab experiments are based on a sea-level atmosphere. Cooling difficulties may be anticipated at cabin pressures below 12.5 psia (5,000 feet altitude equivalent). Also, the Spacelab module materials are rated for a maximum $O_2$ concentration of 23.8%. Hence, this study considers all Spacelab module payloads to be potentially pressure sensitive.

Carry-on experiments are small payloads packaged into mid-deck lockers or stored on a mid-deck panel. Only five carry-ons have been identified to date: plant lignification, blood drawing, OSTA-2 flight deck camera, electrophoresis, and latex dispersion. The first three of these are currently scheduled to fly with STS 2, 4, 8 and 14. The last two have not yet been assigned to a flight. None of these five carry-ons is pressure sensitive. However, approximately 800 carry-on experiments are being considered, many from high schools and universities. Many of these experiments are expected to have pressure sensitive functions and/or cooling requirements.

The chart overleaf shows the operating envelope for pressure sensitive payloads.




ENVELOPE FOR PRESSURE-SENSITIVE PAYLOADS

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# EVA PLANNING

STS planning identifies three categories of EVA

- Planned - EVA is the baseline mode for accomplishing mission objectives. Mission support equipment is designed for operation by EVA.

- Backup - EVA is the backup mode for accomplishing mission objectives. Mission support equipment is designed for EVA to back up select nonredundant features.

- Contingency - EVA is a contingency mode for supporting safe return of the Orbiter to Earth. Tile repair and payload bay door closure are examples.

## Planned EVA

Current planning calls for demonstration EVA's on STS-2 and -4. No other planned EVA's have been identified for the 79 flights identified thus far. Space Telescope is the one payload currently being designed for EVA service. Telescope service has not yet been assigned to a flight. The telescope launch has been assigned to STS-16 and scheduled for launch during 1984.

The 25 KW Power System, currently being concepted, will probably use EVA as baseline. Its launch flight has not been assigned or scheduled to date. Future structures and satellites are expected to make increasing use of baseline EVA.

## Backup EVA

IUS is the only payload element designed for backup EVA. Its erector in the payload bay is designed for EVA assistance if it fails. PAM-A, a payload in the planning stage, is expected to use EVA, but flight assignment and schedule have not been made to date.

## Contingency EVA

EMU's are carried on each STS flight to cover the requirement for contingency EVA. In situations requiring contingency EVA, loss of experimental data, experimental time, or experimental equipment becomes secondary to returning the Orbiter safely to Earth. STS flight plans contain provision for contingency EVA on all flights. Hence payload flight assignment is not affected by the possibility of performing contingency EVA on any particular flight.

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EVA - 3 TYPES

- PLANNED - BASELINE FOR P/L's
- BACKUP - ALTERNATE FOR P/L's
- CONTINGENCY - SAFE RETURN

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EVA Planning (Continued)

The accompanying chart presents a year-by-year summary of planned STS flights and highlights potential conflicts between flights carrying pressure sensitive payloads and flights with planned or backup EVA. The following conclusions can be drawn:

- At the present time there is no planned or backup EVA anticipated for flights with pressure sensitive payloads.
- Carry-on experiments represent uncertainty. Because pressure sensitivity and flight assignment for most carry-ons have yet to be determined, carry-ons represent the major source of potential conflict between EVA and pressure sensitive payloads out through current flight assignment planning, which is September, 1986.

Uncertainty about payloads assignment increases in the future. This study is based on the NASA Flight Assignment Baseline. This document is a moving target, and is updated quarterly to reflect program impacts and other changes. Payload integration planning using this document extends out to Spacelab D-1, which is assigned to STS-25 and scheduled for launch in August, 1984. Beyond that, most, payloads are firm, i.e., individual payloads identified and grouped into a single payload for delivery by a single flight to a particular orbit, out to STS-44, scheduled for launch September, 1985. Other payloads scheduled for launch out to September, 1986 may be less certain. Many of these are reflights, payloads of opportunity or others that have not yet been officially booked. Booked means a payload has been defined, its launch need date established, and it has been budgeted or its earnest launch money has been deposited. Looking beyond 1986 reveals still more uncertainty. As already mentioned, Space Telescope service has not been assigned to a flight. Other payloads such as 25 KW Power System are still in the planning stage. The correlation between flight assignments for EVA payloads and pressure sensitive payloads is undefined in this time period.

## CORRELATION BETWEEN PRESSURE SENSITIVE PAYLOADS AND EVA

| YEAR | FLIGHTS PLANNED | FLIGHTS W/EVA PLANNED | FLIGHTS W/EVA BACKUP | FLIGHTS W/PRESSURE SENSITIVE PAYLOADS MODULE | FLIGHTS W/PRESSURE SENSITIVE PAYLOADS CARRY-ON | POTENTIAL CONFLICTS |
|---|---|---|---|---|---|---|
| 1981 | 3 | 1 (STS - 2) | 0 | 0 | 0 | NONE |
| 1982 | 4 | 1 (STS - 4) | 2 (STS - 5, 7) | 0 | TBD | NONE AT PRESENT. AVOID PSC'S W/PAYLOADS ASSIGNED TO STS - 5 & 7. |
| 1983 | 8 | 0 | 2 (STS - 12, 15) | 1 (STS - 10) | TBD | NONE AT PRESENT. AVOID PSC'S W/PAYLOADS ASSIGNED TO STS - 12 & 15. |
| 1984 | 17 | 0 | 2 (STS - 18, 19) | 4 (STS - 20, 22, 25, 30) | TBD | NONE AT PRESENT AVOID PSC'S W/PAYLOADS ASSIGNED TO STS - 18 & 19. |
| 1985 | 24 | 0 | 2 (STS - 35, 36) | 3 (STS - 38, 48, 6V) | TBD | NONE AT PRESENT. AVOID PSC'S W/PAYLOADS ASSIGNED TO STS - 35 & 36. |
| 1986 | 23 | 0 | 1 (STS - 59) | 3 (STS - 54, 10V, 6B) | TBD | NONE AT PRESENT. AVOID PSC'S W/PAYLOADS ASSIGNED TO STS - 59. |
| TOTAL | 79 | 2 | 9 | 11 | TBD | |
| FORESEEABLE FUTURE (MIDDLE '80'S TO EARLY '90'S) | | TBD (ST SERVICE, 25 KW PS) | TBD | TBD (S/L MODULES) | TBD | AVOID PSC'S ON FLIGHTS TO SUPPORT ST SERVICE AND 25 KW PS DEPLOYMENT/CONSTRUCTION. |
| | | (SATELLITE SERVICE, SOC) | | — | TBD | AVOID PSC'S ON FLIGHTS TO SUPPORT SATELLITE SERVICE AND SOC DEPLOYMENT/CONSTRUCTION. |

PSC'S = PRESSURE SENSITIVE CARRY-ON EXPERIMENTS
STS = SPACE TELESCOPE
25 KW PS = POWER SYSTEM
SOC = SPACE OPERATIONS CENTER

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## APPROACHES FOR AVOIDING CONFLICT BETWEEN EVA AND PRESSURE-SENSITIVE PAYLOADS

The following approaches are not mutually exclusive. A workable compromise between conflicting requirements of EVA and pressure sensitive payloads requires employing all approaches.

- Continue present practice of not assigning module payloads to flights planned for EVA support - This approach retains present module materials and experiments, and hence has no impact on the payload user community.

- Assign pressure sensitive carry-ons to non-EVA flights - The preceding chart shows that no conflict exists at present for 1981 flights because there are no pressure sensitive payloads scheduled for launch in 1981.

  In 1982 three out of four flights may use EVA. With no pressure sensitive payloads identified to date for 1982, it appears likely that several such carry-ons, if identified, could be assigned to the one non-EVA flight.

  By 1983 carry-on traffic is expected to increase. While only two out of eight flights may use EVA, some difficulty may be found in assigning pressure sensitive carry-ons to the remaining six flights. The most desirable situation would be to assign any pressure sensitive carry-ons to the Spacelab 1 flight, which already carries a pressure sensitive module. Similar situations exist in 1984 and 1985, where it would be desirable to assign pressure sensitive carry-ons first to module flights and second to deployment flights for which no baseline or backup EVA is planned. This approach appears workable for the next few years while carry-on traffic is light. Scheduling difficulties might be encountered as carry-on traffic gets heavier. This approach retains present carry-on materials usage and equipment design, and hence has no adverse impact on the carry-on user community.

- Operate Orbiter as a two-pressure vehicle - Equip Orbiter with a two-schedule automatic cabin pressure control system which allows 14.7 psia operation when carrying pressure sensitive payloads, but permits reduction of cabin pressure to support EVA during satellite service and deployment and structure construction flights.

- Raise EVA pressure - This issue is discussed overleaf.

- APPROACHES TO AVOID CONFLICT BETWEEN EVA AND PRESSURE SENSITIVE P/L's.

(1) CONTINUE ASSIGNMENT OF MODULES AND DEPLOYMENT-SERVICE-CONSTRUCTION TO DIFFERENT FLIGHTS.

(2) DO NOT ASSIGN PSC's TO FLIGHTS WITH PLANNED OR BACKUP EVA.

(3) OPERATE ORBITER AT 2 PRESSURES:

- REDUCED $P_{CAB}$ - FLIGHTS WITH PLANNED OR BACKUP EVA.
- 14.7 PSIA - OTHER FLIGHTS.

(4) RAISE EVA PRESSURE.

# RAISE EVA PRESSURE

Raising EVA pressure will permit assigning carry-ons to non-Spacelab module flights with planned or backup EVA. Raising EVA pressure to 5.56 psi will permit lowering cabin pressure during pre-EVA activities to 11.6 psia. The accompanying chart shows that 11.6 psia permits physiologically safe $O_2$ levels without exceeding material standards to which carry-ons are being designed. This removes the materials constraint and allows assigning carry-ons that can operate at 11.6 psia to flights with planned or backup EVA. EMU modifications are required to raise EVA pressure to 5.56 psia.

EVA flights are expected to increase significantly in 1986 and beyond to support projected satellite service and construction activity. This may reduce scheduling opportunities for carry-ons which do not function at subatmospheric pressures. Raising EVA pressure to 7.25 psia will permit use of 14.7 psia cabin pressure even during EVA support. This would lift all constraints and resolve all conflicts in assigning pressure sensitive payloads to flights with planned or backup EVA.

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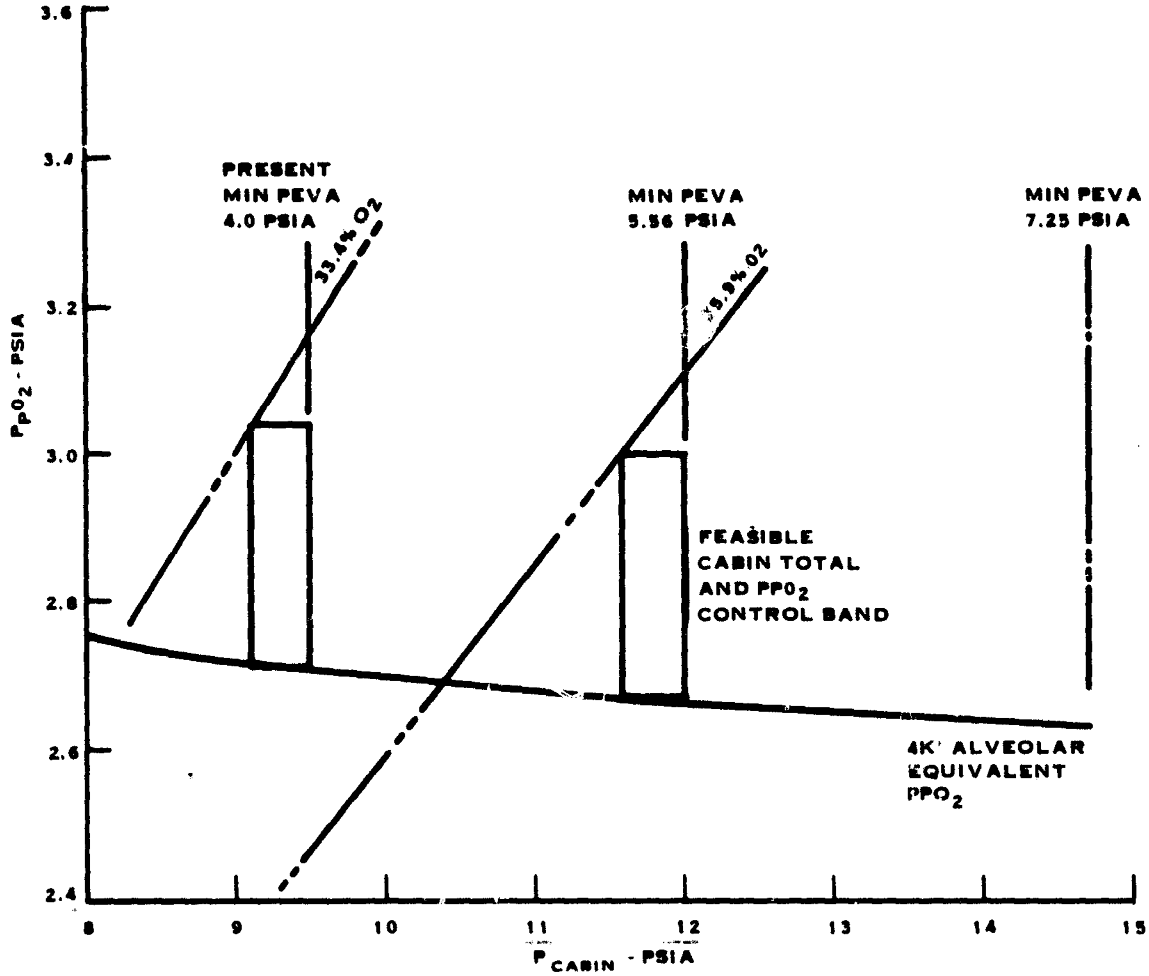
## EFFECT OF RAISING EVA PRESSURE



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# ECWS PREBREATHE ELIMINATION STUDY
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- Cabin Pressure Control
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EMU IMPACTS

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## CONSUMABLES

A complete discussion of consumables issues is contained in the appendix to this report. The issues were developed with cooperation from people at NASA JSC EC2 and EC3 and MDAC TSC. The discussion is based on current mission planning and analysis for STS-1, as modified by projected revisions to support operational flights, and are updated cabin puncture case analysis.

### Reference Mission

Analysis of Orbiter ECLSS atmosphere consumables is based on a 4-person, 7-day mission. Current flight assignment planning shows this mission to combine longest duration and largest crew with payload deployment. The only flights currently planned to fly with larger crews are associated with Spacelab, for which no EVA is planned. Salient points are shown on the accompanying chart.

## REFERENCE MISSION

| | | |
|---|---|---|
| Crew Size | 4 people | |
| Mission Duration | 7 days | |
| Cabin Pressure Profile | <u>PCAB</u> | <u>Time</u> |
| | 14.7 psia | 0 - 8 hours |
| | Reduced | 8 - 166 |
| | 14.7 | 166 - 168 |
| Cabin Leakage | 8.2 lb/day @ 14.5 psia, $PPN_2$ = 11.3 psia. $PPO_2$ = 3.2 psia | |
| Cabin Volume | 2,325 $ft^3$ | |
| Airlock Volume | 150 $ft^3$ | |
| Metabolic Consumption | 0.0739 lb/man-hour @ 450 Btu/hr | |
| Cabin $PPO_2$ | Nominal $PPO_2$ control point is 4,000 feet alveolar equivalent (+) 0.165 psi | |
| EMU purge during donning | 0.83 lb $O_2$ | |
| EMU recharge | 1.217 lb $O_2$ | |
| MMU recharge (2 MMU's) | 40 lb $N_2$ prior to 2nd payload support EVA | |

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# CONSUMABLES USAGE

Cryo $O_2$, $GN_2$ and emergency GOX are the ECLSS consumables considered in this study.

## Cryo $O_2$

The ECLSS draws Cryo $O_2$ from tanks which are part of the Power Reactant Supply and Distribution System. Fuel cells account for over 92% of Cryo $O_2$ consumption. For STS-1, 112 pounds of Cryo $O_2$ was allocated for ECLSS use. Projected Cryo $O_2$ use for the design reference mission is approximately 117 lb at 14.7 psia and 109 lb at 9 psia cabin pressure. The chief contributor to the consumption drop at lower cabin pressures is the cabin puncture contingency which draws from the emergency GOX supply sooner at 9 psi, relieving some demand on Cryo stores.

## Emergency GOX

GOX is not seriously affected by lowering cabin pressure. Tankage margin decreases from approximately 30% (10 lbs) to 20% (14 lbs) primarily due to the cabin puncture contingency.

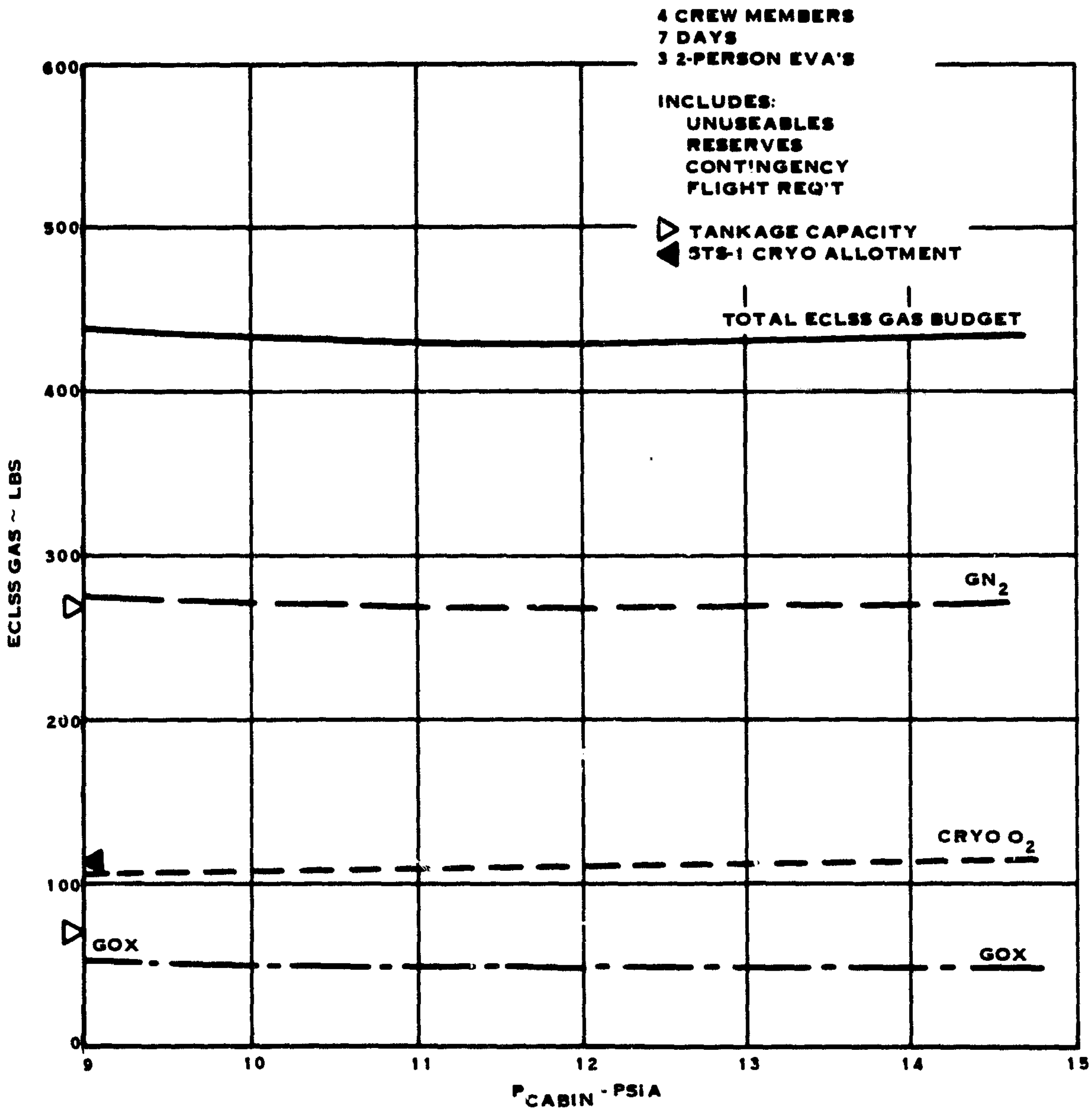
## $GN_2$

Existing $N_2$ tankage has a slight negative margin at all cabin pressures. The negative margin ranges between approximately 0.6% (1.6 lb) and 2.5% (6.6 lb).

The accompanying chart shows the $GN_2$ budgets to be slightly negative for all cabin pressures. Operation with negative margin with present mission rules defining contingency provisions requirements may call for adding a fifth $GN_2$ tank. These tanks are made of titanium, weight 55 lbs, and hold approximately 67 lbs of $GN_2$. They are located in the mid-fuselage area. Space for a fifth tank is at a premium.

The significant contributors to negative margin are the Flight Requirements for MMU recharge and cabin repressurization and the Contingency Requirement to cover cabin puncture. STS-1 mission rules permit minimizing this contingency provision by considering a cabin puncture contingency to use an available portion of the Flight Requirement to repressurize the cabin backup to 14.7 psia prior to reentry which would not be used in the event of a cabin puncture.

## ORBITER ECLSS GAS CONSUMABLES USAGE



# CONSUMABLES USAGE ANALYSIS

Analysis of consumables usage leads to the following conclusions:

- Consumables usage is essentially independent of cabin pressure for each of the three consummables. This is shown on the previous chart.
- Total ECLSS gas budgets, consisting of reserves, contingencies and flight requirements for all three atmosphere consumables added together, increase approximately only one pound (from 437 lb to 438 lb) as cabin pressure is lowered from 14.7 to 9 psia nominal. The total net change is composed of offsetting effects which are significantly sensitive to cabin pressure, as shown in the accompanying tabulation.
- The major contributor to increased consumables use at reduced cabin pressure is the flight requirement to repressurize the cabin to 14.7 psi prior to reentry (approximately 66 lb from 9 psia).
- These increases are partially offset at lower cabin pressures by reductions in gas quantity required to repressurize the airlock after payload EVAs (approximately 17 lb), in cabin gas leakage (approximately 21 lb), and in the net contingency requirement to hold cabin pressure at a minimum of 8 psia for 160 minutes following a cabin puncture (approximately 27 lb).
- Present LiOH budgets appear acceptable for cabin pressures down to 9 psia nominal.

CONSUMABLES USAGE ANALYSIS*

| | PCAB, psia 9.0 | 14.7 | Net Change |
|---|---|---|---|
| Dispersion Allowance | 22.94 lb | 20.05 lb | 2.89 lb |
| Net Cabin Puncture Contingency | 125.72 | 152.4 | -26.68 |
| Net Line Items for Other Worst Case Contingencies | 1.37 ($GN_2$) | 5.54 (GOX) | -4.17 |
| Cabin Leakage | 86.97 | 104.68 | -20.71 |
| A/L Repress (Flight Req't Only) | 36.01 | 52.81 | -16.8 |
| Cabin Repressurization | 66.77 | 0.0 | 66.77 |
| | 339.78 lb | 338.48 lb | 1.3 lb |

*For Cryo $O_2$, GOX and $GN_2$ added together.

## AIR-COOLED AVIONICS

A complete discussion of the air-cooled avionics issues is contained in the appendix to this report. The issues were developed with cooperation from people from Rockwell International and McDonnell Douglas Technical Services Company. The investigation is based on identifying cabin environment and electronic load management conditions that retain the same avionic-box surface temperature that exists in a sea level cabin. Significant findings are as follows:

- The present requirement is for cooling air exit temperatures not to exceed 130°F.

- At reduced cabin pressure, the heat transfer coefficient between the avionics box and the cooling air degrades as the 0.8 power of the pressure ratio, requiring the permissible air outlet temperature to be less than 130°F to retain the same box temperature, as shown in the accompanying chart. Basing the analysis on this consideration insures that electronic component life is not shortened by overheating at reduced cabin pressure.

- Operation at down to 11.6 psia cabin pressure is feasible under the following conditions, as shown on the following charts.

    - Cabin thermal environment is nominal solar exposure.

    - Crew size is 4 or less.

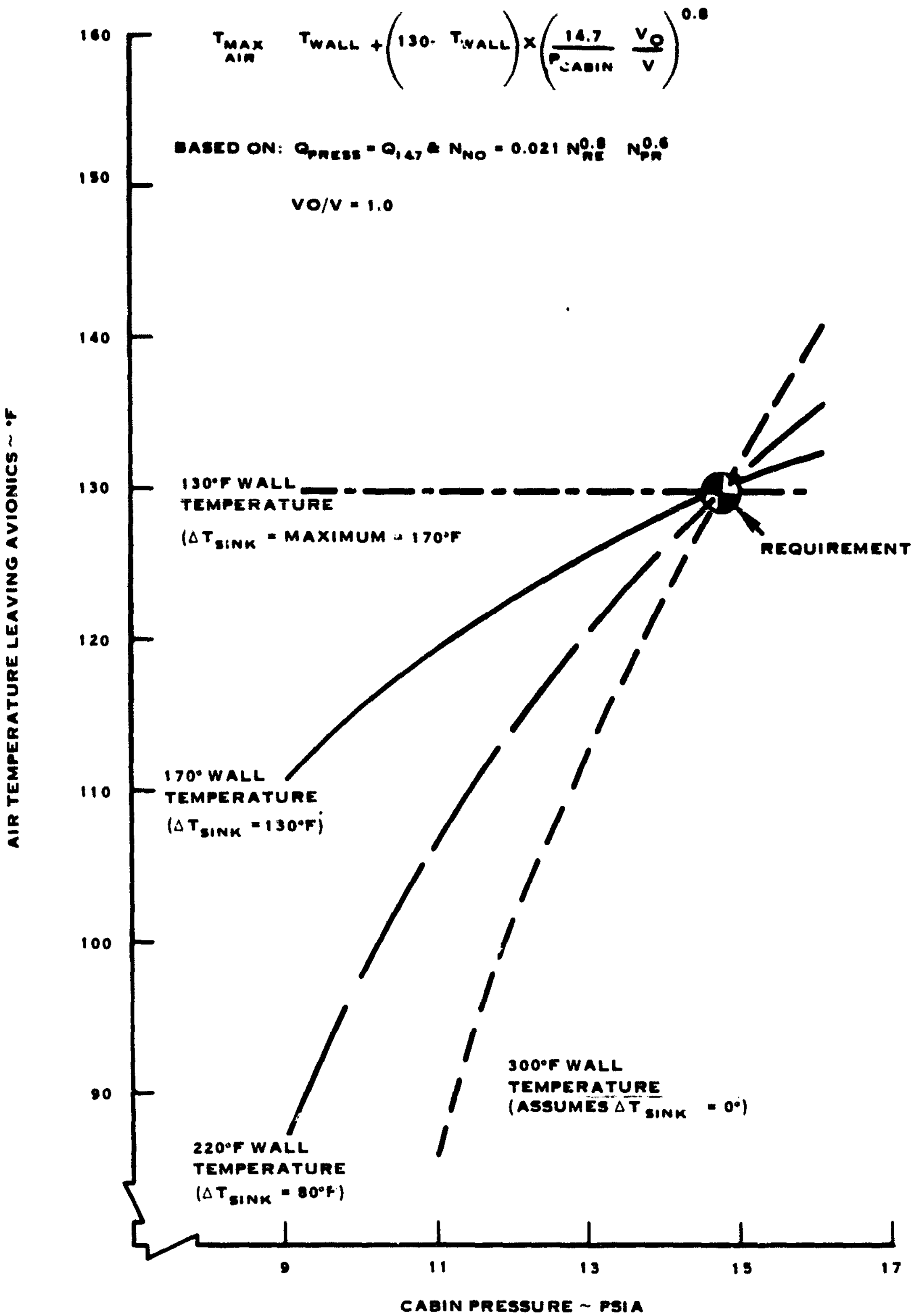
    - Avionic boxes are designed for nominal wall temperature of 170°F or less.

    - One general purpose computer (GPC) load is shifted from Avionics Bay 1 to Avionics Bay 3.

    - 1 IMU is powered down.

- If the above conditions are exceeded, some power down of flight deck electronics will be necessary. However, these will not exceed those planned for STS-1 Priority Power-downs 1 through 3.

## EFFECT OF WALL TEMPERATURE ON MAXIMUM AIR TEMPERATURE



## CREW SIZE FOR EVA FLIGHTS

The accompanying table shows most flights planned to date have EVA associated with crew sizes of 2 and 3 people. No flights with crews in excess of 4 people have planned or backup EVA. Hence a crew size of 4 is the current maximum for considering EVA on a regular basis, and becomes a basis for the avionics-cooling analysis.

## CREW SIZE

| Crew Size | Number of Flights | Type EVA Planned |
|---|---|---|
| 2 | 11 | 2 - Planned<br>6 - Backup<br>3 - Contingency |
| 3 | 19 | 3 - Backup<br>14 - Contingency<br>2 - TBD |
| 4 | 5 | 3 - Contingency<br>2 - TBD |
| 6 | 16 | 16 - Contingency |
| TBD | 28 | TBD (DOD Flights) |
| TOTAL | 79 | |

Planned - EVA is the baseline mode for accomplishing mission objectives. Mission support equipment is designed for operation by EVA.

Backup - EVA is the backup mode for accomplishing mission objectives. Mission support equipment is designed for EVA to backup select nonredundant features.

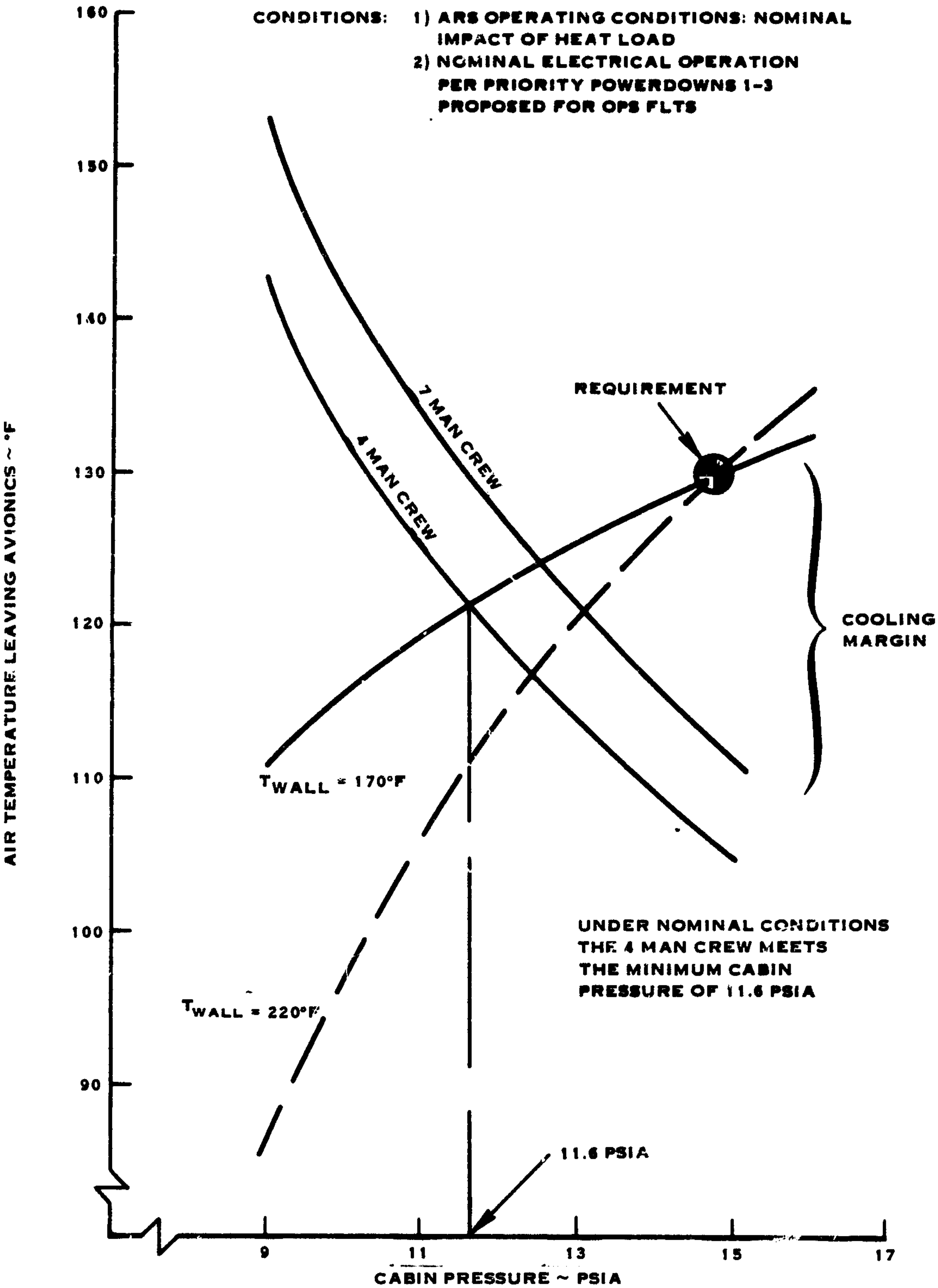
Contingency - EVA is a contingency mode for supporting safe return of the Orbiter to Earth. Tile repair and payload bay door closure are examples.

SOURCE: JSC 13000-5 "Flight Assignment Baseline", December, 1980.

FLIGHT DECK AVIONICS

The accompanying chart shows will a 4 person crew and nominal solar heat load the cabin electronics that are normally powered-up while on orbit will be adequately cooled at 11.6 psia minimum cabin pressure, if the avionics boxes are designed for 170°F wall temperature at the sea level condition.

FLIGHT DECK AVIONICS ♦ NOMINAL COOLING MARGIN



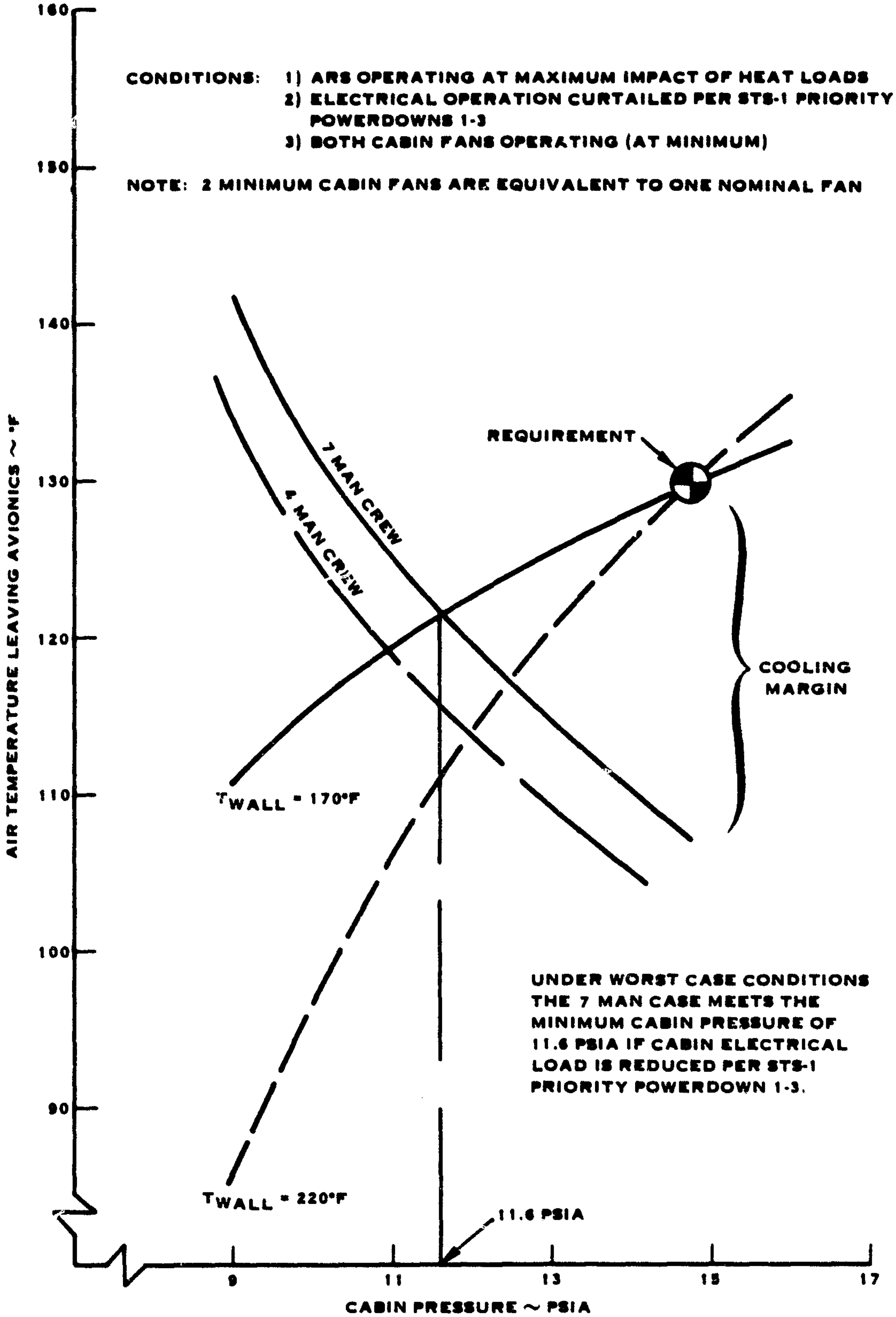
Flight Deck Avionics (Continued)

The accompanying chart shows that sufficient cooling exists at 11.6 psia minimum cabin pressure under worst case conditions, if cabin electrical loads are curtailed per STS-1 Priority Power-downs 1 through 3. This chart is based on a crew size of 7, maximum solar exposure, and minimum performance of cabin fans and interface heat exchanger. Both cabin fans are running.

STS-1 priority power downs 1 through 3 turn off the following cabin equipment in addition to equipment proposed to be powered down during the orbital phase of operational flights:

| | | |
|---|---|---|
| - 1 | Data Display CRT and Associated Drivers | 417 watts |
| - 2 | TV Monitors | 40 |
| - 2 | Payload Specialist Stations | 216 |
| - 1 | GFE Tape Recorder | 114 |
| - 1 | Cabin Floodlights | 1,085 |
| | TOTAL | 1,872 watts |

## FLIGHT DECK AVIONICS - WORST CASE SYSTEM OPERATING CONDITIONS



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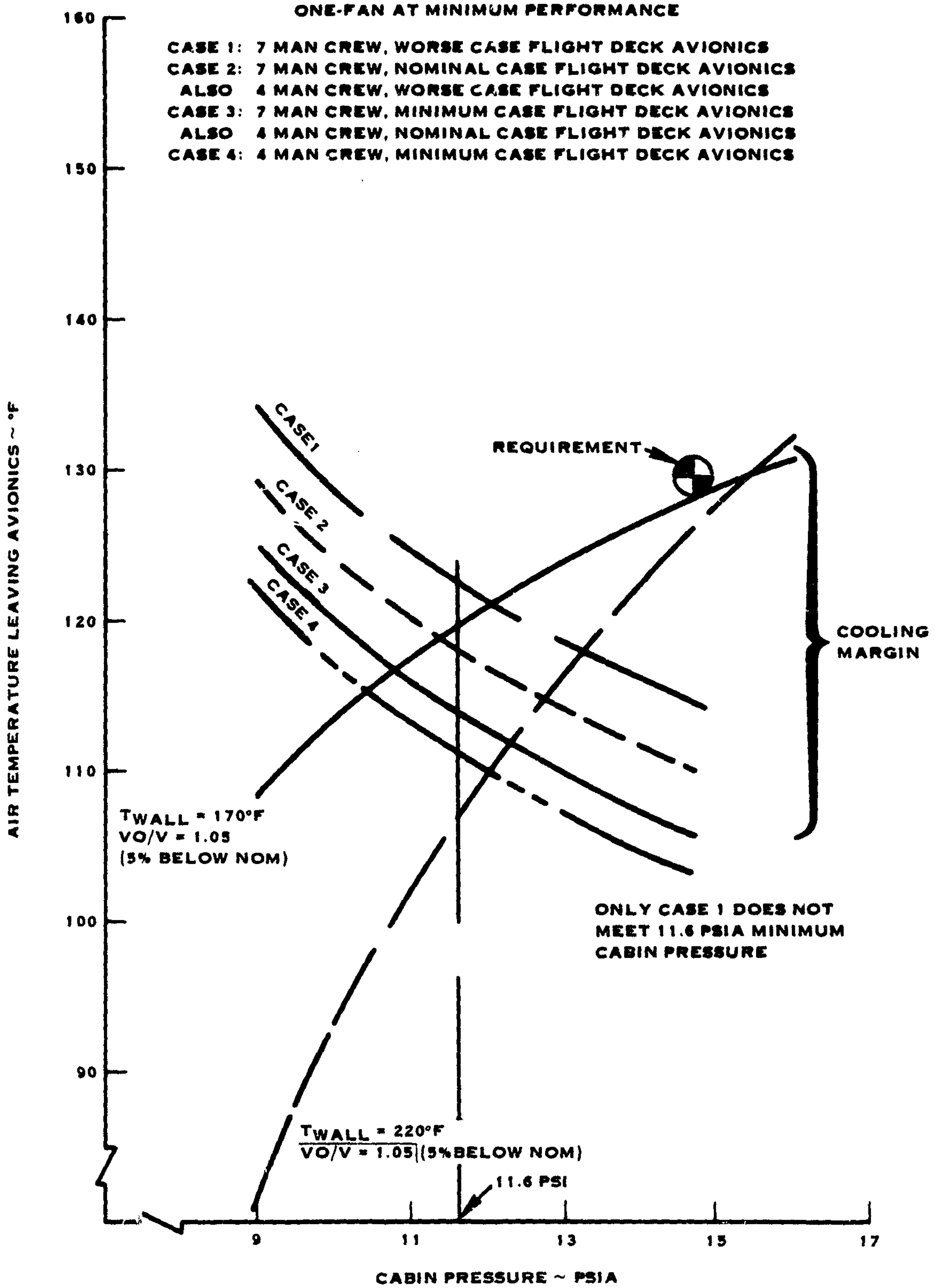
## AVIONICS BAYS 1 AND 2

Planned use of GPC's on orbit calls for operating units 1 and 4 in Avionics Bay 1 and unit 2 in Bay 2. Unit 5 in Bay 2 and Unit 3 in Bay 3 are shut down. The accompanying chart shows that with one GPC down in Bays 1 and 2, adequate cooling exists down to 11.6 psia for all 4-person and most 7-person cases.

This study recommends operating only one GPC in Bay 1 at reduced cabin pressure, and shifting the contents of that memory to GPC 3 in Bay 3. Analysis shows that this does not cause any overheat problem in Bay 3.

## AVIONICS BAY NO. 1/2 ♦ PROPOSED CASE

**CONDITIONS: ALL AIRCRAFT AVIONICS OFF AND 1 CPU, 1 IOP OFF ONE-FAN AT MINIMUM PERFORMANCE**



## IMU's

The accompanying chart shows the IMU's operating with one IMU fan operating and one IMU shutdown. This the normal mode for operational flights. The analysis shows that cooling is adequate down to 11.6 psia at nominal heat levels and four person crew.

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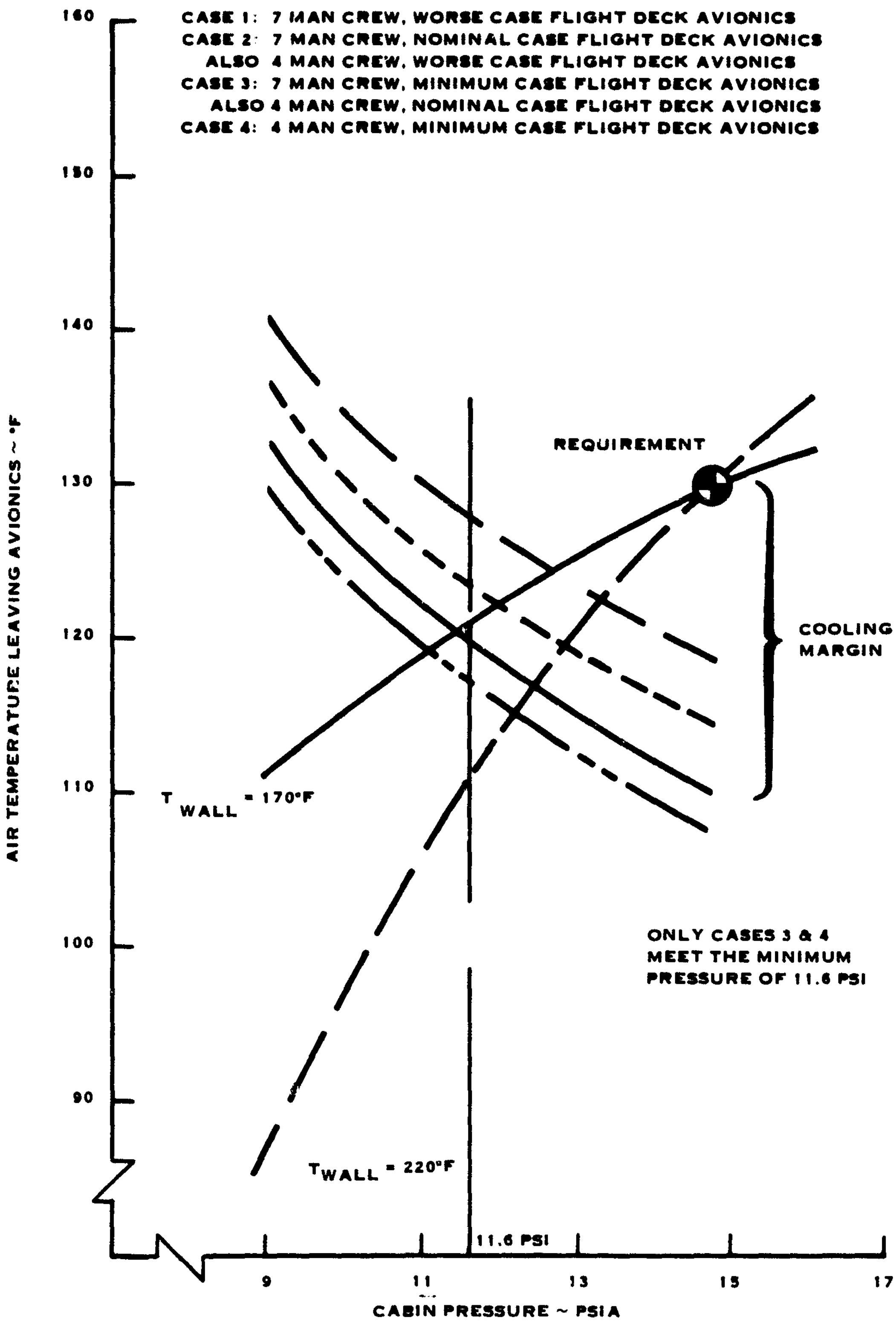
INERTIAL MEASURING UNITS ♦ POWER/DOWN CASE



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## CABIN PRESSURE CONTROL

A complete discussion of cabin pressure control issues is contained in the appendix to this report. The issues were developed with cooperation from people from NASA JSC EC3 and NS2, Rockwell International Space Division and Carleton Controls. The investigation is based on minimizing the cabin $PPO_2$ control band using present or available Orbiter equipment. Significant findings are as follows:

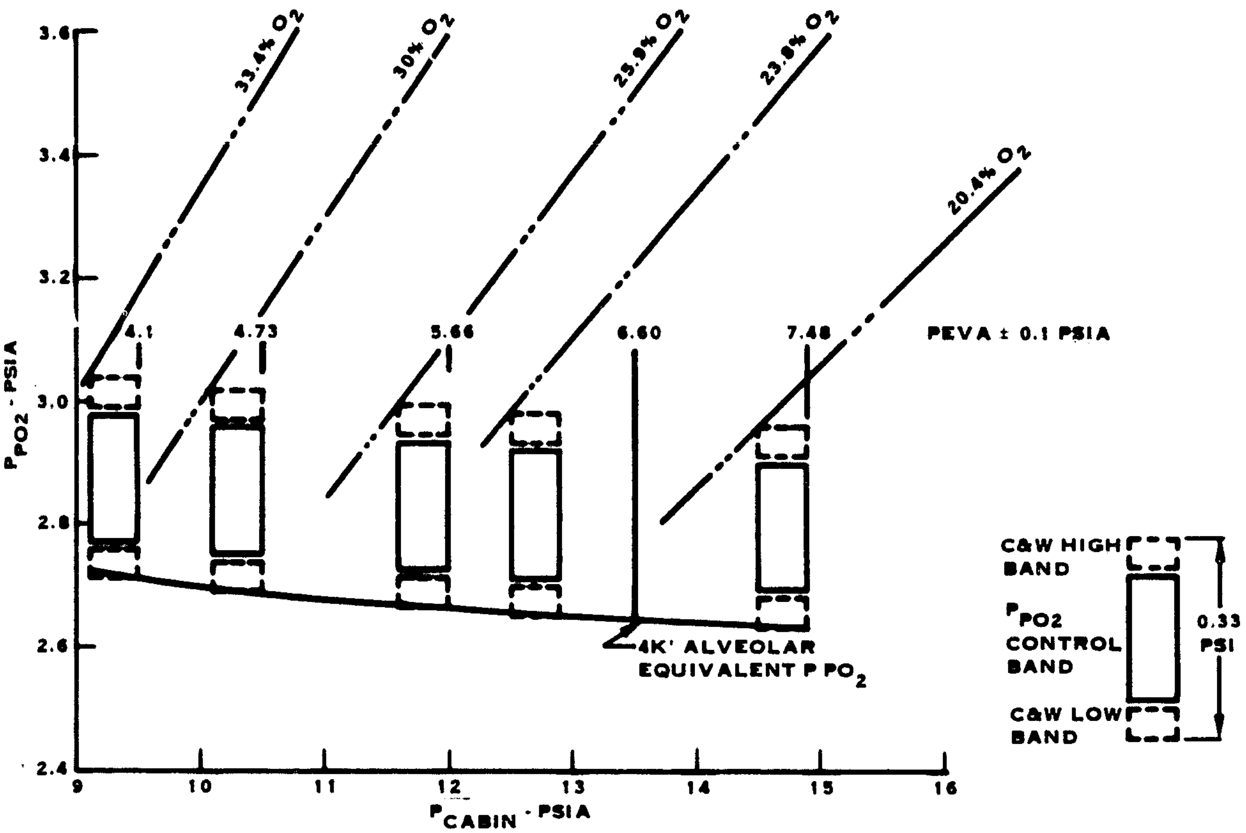
- It appears feasible to control and annunciate cabin $PPO_2$ within a total band of 0.33 psi using the existing cabin $O_2/N_2$ controller, the new 1.5% $PPO_2$ sensor and new C&W limit proms. These limits are developed on subsequent pages of this report section.

- The 0.33 psi $PPO_2$ control band permits reduction of cabin pressure down to 10.3 psia nominal, while retaining $PPO_2$ between the minimum physiological limits and maximum materials compatibility limits deemed acceptable for STS-1 EVA support (30%). Cabin pressure can be reduced to 11.8 psia nominal without exceeding the 25.9% $O_2$ deemed acceptable for normal STS-1 operation, or 12.5 psia nominal without exceeding 23.8% $O_2$, the present Spacelab upper $PPO_2$ limit.

- Addition of a third mechanical regulator permits operation of the Orbiter at reduced cabin pressure for EVA flights while retaining 14.7 psia cabin pressure for Spacelab Module flights.

Cabin Pressure Control - The accompanying chart shows how the combination of minimum alveolar $PPO_2$ and maximum cabin $O_2$ concentration defines a "corner" which defines the range of allowable cabin pressures. Minimum EVA pressure, which simplifies suit mobility issues, seeks the lowest cabin pressure. The smallest cabin $PPO_2$ control and annunciation band permits the lowest cabin pressure consistent with physiological and materials limits.

STS CABIN GAS PRESSURE RELATIONSHIPS



Cabin Pressure Control (Continued)

Orbiter cabin pressure control is shown schematically in the accompanying chart. There are two completely separate systems from tankage to gas inlets into the cabin. Crew-selectable cross-over valves permit interconnection modes. In each system cabin total pressure is controlled by a mechanical regulator located adjacent to middeck panel M010W, near the head. Each system has an $O_2$ partial pressure sensor, located in the aft middeck ventilation circuit duct, which senses $O_2$ concentration. An $O_2/N_2$ controller, located behind panel M010W, responds to low $O_2$ concentration by closing the $N_2$ supply valve that feeds the cabin pressure regulator. Cabin pressure is thus made up with $O_2$ until the $PPO_2$ concentration is satisfied. The $O_2/N_2$ control then responds by opening the $N_2$ valve, which allows intermediage $N_2$ supply pressure at 200 $\pm$ 15 psig to supply the cabin pressure regulator. This intermediate $N_2$ pressure, upstream of the cabin pressure regulator, causes the intermediate $O_2$ supply regulator, set to 100 $\pm$ 10 psig, to close, assuring that only $N_2$ is supplied to the cabin pressure regulator.

For STS-1 total cabin pressure was set at 14.5 $\pm$ 0.2 psia. $PPO_2$ was set at 3.2 $\pm$ 0.25 psig with nominal C&W limits at 2.8 and 3.6 psia. This control band is too wide to permit significant reduction in cabin pressure to support EVA without prebreathe. Thus STS-1 baseline procedures call for manual control of cabin pressure and $PPO_2$ at lower settings to support EVA. However, NASA JSC safety requirements dictate use of automatic cabin pressure control for EVA support for operational flights.

The payloads analysis in a previous section of this report identifies advantages of operating the Orbiter as a two-pressure vehicle, namely at 14.7 psia for Spacelab Module flights and at reduced cabin pressure for payload deployment flights. This could be accomplished as shown in the accompanying chart by resetting the cabin pressure control to the $PPO_2$ limits shown in the preceding chart for the reduced cabin pressure selected and by controlling reduced total cabin pressure by a third mechanical pressure regulator. A manual shut-off valve on panel M010W is required upstream of the third regulator to shut off that regulator when operating on the emergency regulator.

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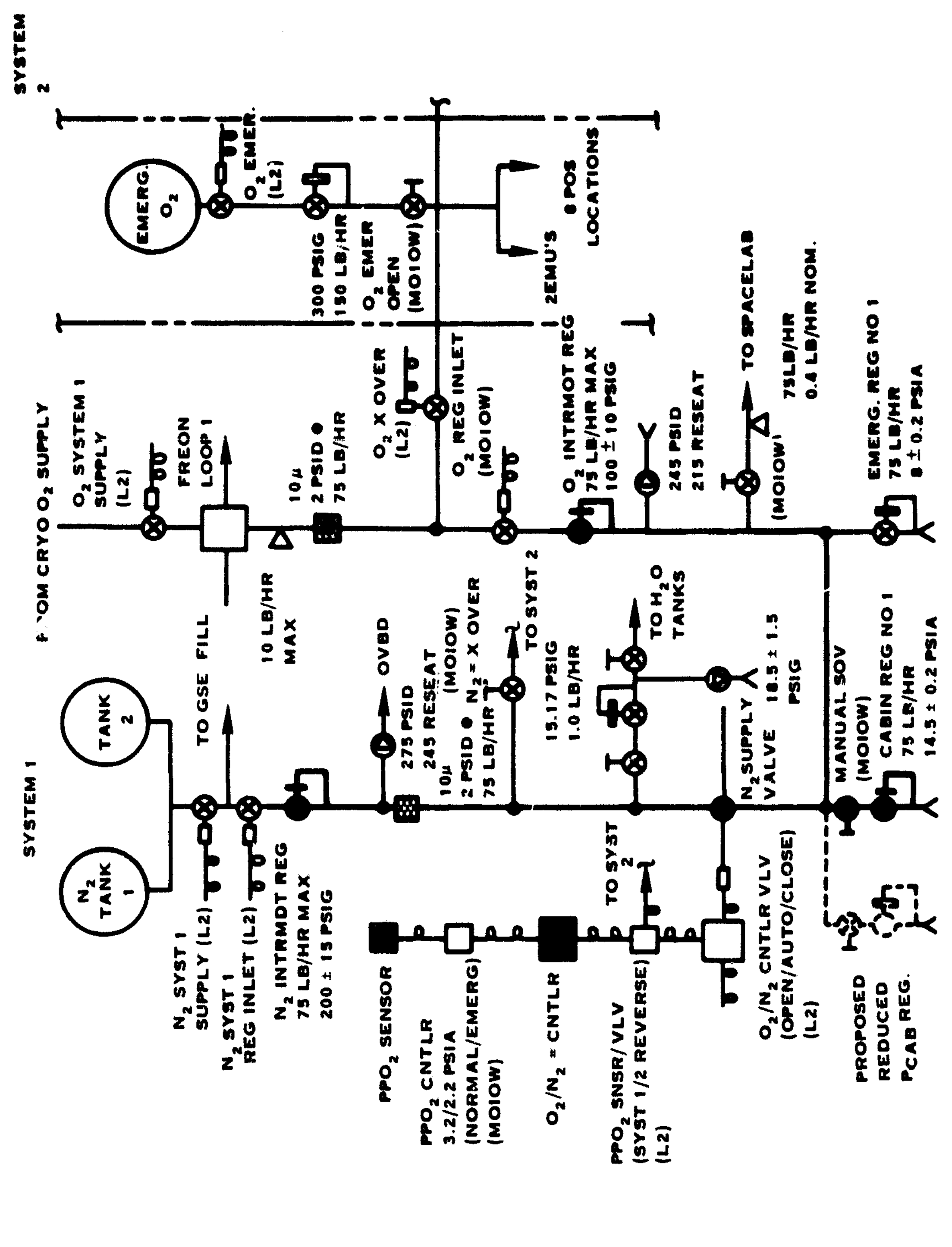
ORBITER PRESSURE CONTROL SYSTEM



## REDUCED $PPO_2$ CONTROL BAND

The accompanying chart shows that the $PPO_2$ control band can be reduced to 0.33 psi using the existing cabin $O_2/N_2$ controller with lowered set point plus the new $\pm$ 1.5% $PPO_2$ sensor, which is presently installed. New C&W limits would also be required. Revised fault detection and annunciation limits can be inputted via keyboard.

REDUCED $PPO_2$ CONTROL BAND

Ground Rules

- Use the same sensor to drive C&W and $O_2/N_2$ controller. This allows elimination of sensor-signal conditioner error from C&W band and leaves C&W error of ± 0.025 psi (± 1 bit/250 bits).

- Reduce dead bands between C&W trip and $O_2/N_2$ control from 0.41 psi to 0.01 psi.

- Use the new ± 1.5% $PPO_2$ sensors in place of the at 3% sensors recently replaced in OV102. Error band is ± 1.5% x 5 psi = 0.15 psi.

- Use RMS to calculate $PPO_2$ sensor-controller error band.

| | | | |
|---|---|---|---|
| Sensor | 0.15 psi | $(0.15)^2$ | = 0.0225 |
| Control | 0.15 psi | $(0.15)^2$ | = 0.0225 |

$$(0.0450)^{1/2} = 0.212 \text{ psi}$$

Total $PPO_2$ Control Band

| | |
|---|---|
| C&W High Limit | 0.05 psi |
| Dead Band | 0.01 |
| Sensor-Controller | 0.21 |
| Dead Band | 0.01 |
| C&W Low Limit | + 0.05 |
| | 0.33 psi |

## CABIN MATERIALS

A complete discussion of Orbiter cabin materials issues is contained in the appendix to this report. The issues were developed with cooperation from McDonnell Douglas Technical Services Company. The significant findings are as follows:

- Existing Orbiter cabin materials have been rated for 25.9% $O_2$ which exists for STS-1 nominal operation at 3.2 psia $PPO_2$ in a 14.5 psia nominal cabin, as shown in the accompanying chart.
- Major use materials (greater than 1.0 lb or 50 $in^2$) in the cabin have been found acceptable for use at 30% $O_2$. This condition exists for STS-1 EVA support, and would exist at a 10.3 psia cabin with minimum $PPO_2$ at the 4,000 feet alveolar equivalent.
- For cabin pressures below 10.3 psia nominal, a materials evaluation is required that is comparable to the investigation performed by NASA JSC ESS to assess 216 major use materials in the Orbiter cabin for use at 30% $O_2$.
- This study identifies a maximum $O_2$ concentration of 33.4% which occurs at 2.88 psia $PPO_2$ in a 9.3 psia nominal cabin.

The list overleaf is a summary of the types and usages of the 216 major use materials evaluated for acceptability at 30% $O_2$. A similar evaluation would be required to identify changes to Orbiter cabin materials to support a $PPO_2$ level of 33.4%.

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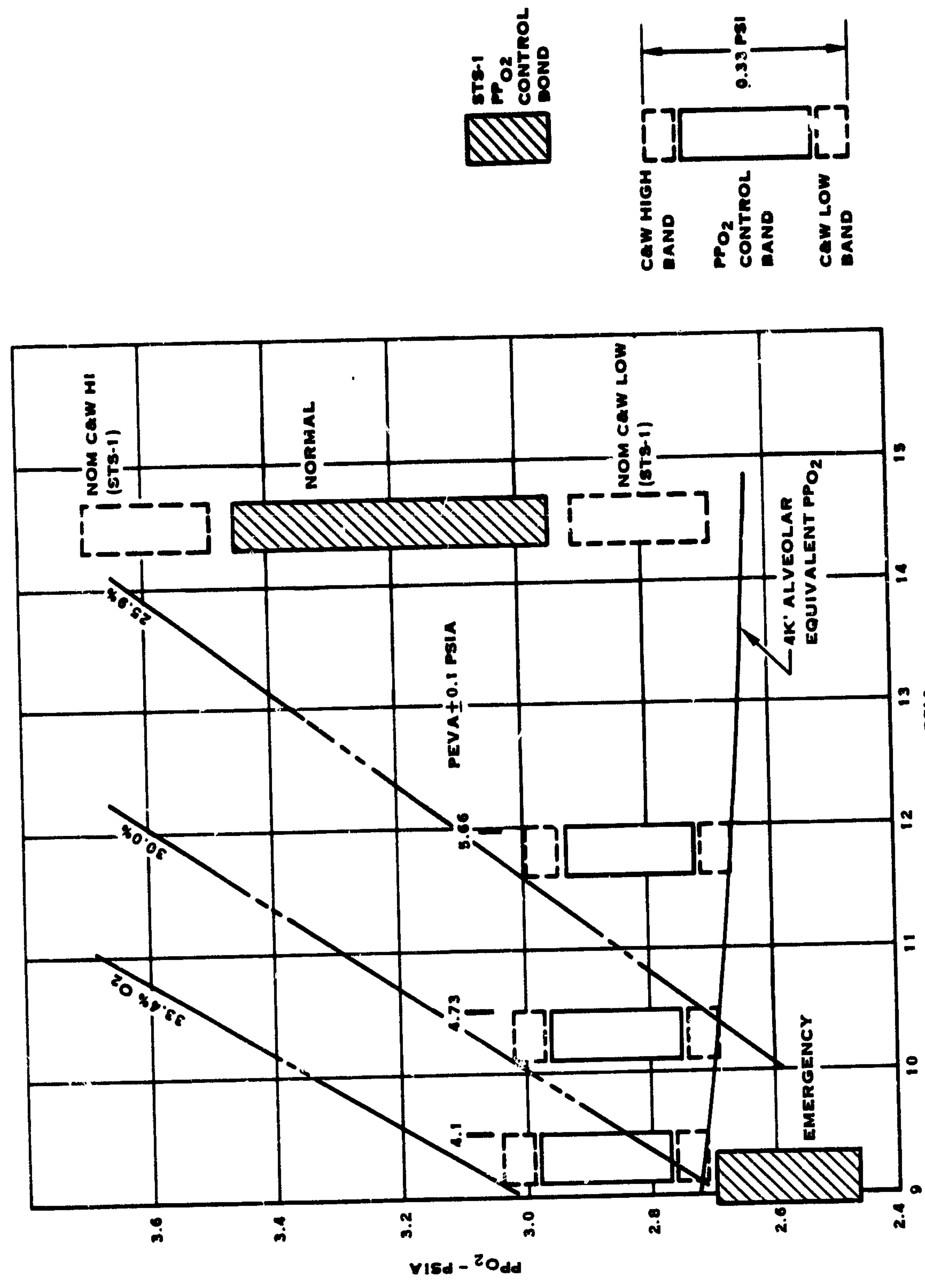
STS CABIN GAS $PP_{O2}$ RELATIONSHIPS



SUMMARY
CREW COMPARTMENT - MAJOR USE MATERIALS

| Piece Parts and Associated Materials | Bulk Materials |
| --- | --- |
| Cushion Clamps | Charcoal |
| Edge Lit Panels | Coatings |
| Filter Materials | Fabrics |
| Gaskets and Seals | Films |
| Shims (Non-metallic) | Foams |
| Sleeving and Tubing | Inks |
| Acrylic Plexiglass | Greases and Lubes |
| Kel-F | Insulated Wire and Cable |
| Lexan | Insulations |
| Nylon | Laminates |
| PCB's | Sound Insulation |
| Rulon | Sponge |
| Silicones | Velcro |
| Teflon and TFE | Webbing and Strapping |
| Viton | Varnishes |

Total: 216 Major Use Materials in Orbiter Crew Compartment

Assembly Materials

Adhesives

Cord and Tapes

Lacing Tape

Molding and Potting Compounds

Selants

Source: Rockwell International
Matco Report U719-10-111
10-8-80, updated 3-13-81

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ECWS PREBREATHE ELIMINATION STUDY
FINAL REPORT

- O INTRODUCTION
- O EXECUTIVE SUMMARY
- O PHYSIOLOGY
- O PRE-EVA PROCEDURES
- O PAYLOADS
- O ORBITER IMPACTS
- ● EMU IMPACTS
- O TRADE STUDY

## EMU IMPACTS

A complete discussion of EMU impacts is contained in the appendix to this report. This investigation was performed by Hamilton Standard and ILC-Dover and consists of assessments of each EMU CEI operating at increased vent loop pressure. Suit joint samples were run at increased pressure to quantify impacts on mobility.

Overview of Changes - The EMU and POS consist of 22 contract end items (CEI's), comprising 117 component types and major structural elements. The accompanying tabulation shows that most EMU components and all POS components require no change to support operating the EMU at elevated suit pressure.

MOST EMU AND POS COMPONENTS
REQUIRE NO CHANGE FOR
INCREASED EVA PRESSURE

| Total Number of EMU and POS Components | Number of Components Requiring Change to Operate at Higher EVA Pressure | | | |
|---|---|---|---|---|
| | PEVA, psia | | | |
| | 5.25 | 6.00 | 6.75 | 7.50 |
| 117 | 19 | 21 | 22 | 25 |
| % of Components Requiring No Change | 84 | 82 | 81 | 79 |

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## SIGNIFICANT LSS IMPACTS

The accompanying table identifies the EMU LSS CEI changes required to support EVA at higher suit pressures. The SOP, battery and $O_2$ regulators require significant changes, in that extensive redesign is required and development evaluation of the redesign is recommended.

SOP - The SOP is sized to provide purge flow sufficient to limit inspired $CO_2$ to 15 mm Hg for 30 minutes at a metabolic rate of 1,000 BTU/hr. In addition, it is desirable not to increase the risk of the bends while using the SOP. This requires raising SOP operating pressure in step with raising EVA pressure to retain the same ratio of pre-EVA tissue dissolved gas to emergency EVA pressure of 1.9 as the present SOP, which supports emergency EVA at 3.35 psia after crewmember is exposed to a 9.0 psia cabin for 24 hours. The following table shows the rapid increase in SOP capacity required to keep pace with increasing EVA pressure.

| | | | | |
|---|---|---|---|---|
| PEVA, psia | 5.25 | 6.00 | 6.75 | 7.50 |
| % increase in SOP $O_2$ | 29 | 47 | 64 | 82% |

Enlarging the SOP to accommodate additional $O_2$ will impact the PLSS TMG, the AAP lower crossmember, the airlock wall, the "shelf" on the MMU, and may affect the ability of a suited crewmember to pass through the Orbiter interdeck hatch. These impacts are significant and require development evaluation after implementation. HS recommends that SOP requirements and implementation be reviewed to identify acceptable approaches for minimizing these impacts.

Battery - Increasing EVA pressure causes the fan motor to draw more power, increasing power demand on the battery. The following tabulation shows the effects on battery power and volume.

| | | | | |
|---|---|---|---|---|
| PEVA, psia | 5.25 | 6.00 | 6.75 | 7.50 |
| % increase in battery power | 6 | 9 | 13 | 16.4% |
| % increase in battery volume | 0 | 3 | 6 | 10% |

It is expected that up to 6 psia PEVA the battery can be accommodated within the existing PLSS structure. Beyond 6 psia structure will likely require enlargement to accommodate a larger battery. HS recommends that battery requirements and implementation be reviewed to identify acceptable approaches for minimizing impacts to PLSS structure.

$O_2$ Regulators - Resetting the PLSS and SOP $O_2$ regulators requires new springs plus a detailed evaluation of regulator strokes, flow areas and stability, which may require additional changes to regulator detail parts. These changes are expected to be straightforward redesign, but require development evaluation. The changes are not expected to require external envelope changes.

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## SIGNIFICANT IMPACTS TO EMU LSS AND INTERFACING AREAS

| Item | Impact |
| --- | --- |
| SOP | • Increase stored $O_2$ capacity. |
| | • Enlarge SOP package. |
| | - May prevent passage through Orbiter interdeck hatch. |
| | - Interfere with AAP lower crossbar. |
| | - Interfere with MMU "shelf". |
| Battery | • Increase capacity. |
| | • Enlarge battery package. |
| | - May require modification to PLSS structure. |
| AAP | • Relocate lower crossbar. Expected to require relocation of dovetail mounts in Orbiter airlock wall. May require strengthening airlock wall. |
| PLSS & SOP $O_2$ Regulators | • Modify springs to change set points. |
| | • Resize flow orifices as required. |
| | • Evaluate stability. |
| | • Modify piece parts as required to meet flow and stability requirements. |

## MINOR LIFE SUPPORT SUBSYSTEM IMPACTS

The accompanying table identifies impacts to CEI's which are straightforward design changes which are not expected to require development evaluation. These include stiffening flat plate areas exposed to increased differential pressure loading, resizing certain orifices, and resetting certain relief valves and regulators.

Raising EVA pressure requires small increases in water and oxygen to cover small additional cooling and leakage requirements. At 7.5 psia an additional 1.4% water and 2.5% oxygen are required. These increases are too small to warrant changing PLSS tankage. Consumables useage rules should be modified slightly to cover these increases.

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## MINOR IMPACTS TO EMU LSS CEI'S

| CEI | | Impact |
|---|---|---|
| PLSS | - | Strengthen sublimator and pitot-actuated valve. |
| | - | Revise 142, 145, and 146 relief valve settings. |
| | - | Revise 126 and 141 orifices. |
| | - | Revise C&W software limits. |
| DCM | - | Revise pressure gage range. |
| | - | Revise purge valve flow capacity. |
| SCU | - | Revise 418 and 419 regulator settings. |
| CCC | - | Strengthen canister. |

## SPACE SUIT ASSEMBLY IMPACTS

Raising EVA pressure has impacts on SSA strength margins, joint performance, and gloves.

Strength Margins - The following areas require strengthening in proportion to the increase in EVA pressure: axial restraints in the LTA waist and brief, and HUT fiberglass, scye gimbals and bearings.

Joint Performance - The accompanying table presents the results of an evaluation of present EMU joints tested at EVA pressures up to 7.5 psig. The negative numbers represent increases in joint torque over present 4 psig values. Numbers to the right of the broken line represent joints for which new concepts are required to make practical, working joints. Numbers to the left of broken line represent joints that can be improved by extending present joint construction technology.

Gloves - The EMU glove loses dexterity rapidly with increasing EVA pressure. Technology of the present glove does not appear adequate to support a workable glove above the range of 5.25 to 6.0 psia. Hence a new technology initiative is recommended for developing workable gloves for pressures above 5.25 psia.

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## SSA IMPACTED JOINTS

| | PEVA psia 5.25 | 6.00 | 6.75 | 7.50 |
|---|---|---|---|---|
| Shoulder | -15% | -30% | -50% | -65% |
| Waist | -20% | -35% | -40% | -60% |
| Brief/Hip | -10% | -30% | -55% | -70% |
| Elbow | -10% | -20% | -30% | -65% |
| Knee | -10% | -20% | -25% | -35% |
| Ankle | -5% | -10% | -15% | -20% |
| Glove | | | | |

Extend Existing Concepts ← → Require New Concepts

## TESTING AND HANDLING

Increasing EVA pressure raises four issues regarding testing and handling: safety, special test equipment, handling fixtures and integrated testing.

Safety - If pressure garment integrity is lost suddenly (on the order of one second) at approximately 6 psig or above, lung rupturing may occur which releases air into the pleural cavity. A first aid in managing the escaped air is to repressurize the test subject to several atmospheres in a hyperbaric chamber within 10 to 20 minutes. This procedure helps to control both lung collapse and air bubbles in the bloodstream (air embolism). NASA safety standards require access to a hyperbaric chamber when manned testing is conducted at 6 psig or above. Hyperbaric facilities are available at JSC, where all EMU manned testing at EVA gage pressure has been conducted to date.

Special Test Equipment - Test rigs at Hamilton Standard and NASA JSC are compatible with increased EVA pressure, with just minor modifications. Typical changes include recalibration of vent loop instrumentation, resetting of back pressure controls, and modifying or resetting relief valves. A hardware safety philosophy has dictated inclusion of relief valves in test rig-test item interface accessories to preclude advertent isolation of rig-mounted relief valves. These relief valves require resetting or modifications also.

Handling Fixtures - Enlargement of the SOP may require modification of the ground handling device, PLSS/SOP bench fixtures, and CEI 199 shipping container. This assessment would be made at the time of redesign of the SOP.

Integrated Testing - The United States Manned Space Program has conducted all EVA at 4 psia. There is no widespread U.S. experience with higher EVA pressures. A new technology initiative is recommended to conduct an integrated unmanned and manned test program at the selected EVA pressure to gain assurance that issues of higher EVA pressures are well understood and to verify related procedures.

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# ECWS PREBREATHE ELIMINATION STUDY
# FINAL REPORT

- o INTRODUCTION
- o EXECUTIVE SUMMARY
- o PHYSIOLOGY
- o PRE-EVA PROCEDURES
- o PAYLOADS
- o ORBITER IMPACTS
- o EMU IMPACTS
- • TRADE STUDY

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## PREBREATHE ELIMINATION TRADE STUDY

The trade study first uses the issues developed in the course of the Prebreathe Elimination Study to define a window within physiological limits that minimizes impacts to Orbiter, payloads, EMU and operations. Secondly, the trade study locates the best EVA pressure within the window.

The accompanying chart defines the allowable window. It is bounded by the 25.9% $O_2$ limit for cabin materials compatibility, 5.9 psia PEVA corrosponding to the 8 psig maximum sea level suited-test limit for not requiring availability of a hyperbaric chamber, 2.66 psia $PPO_2$ corresponding to the 4,000 foot altitude equivalent alveolar $O_2$ concentration, and 11.6 psia cabin pressure which accepts the minimum cabin $PPO_2$ control band between the minimum and maximum $PPO_2$ limits.

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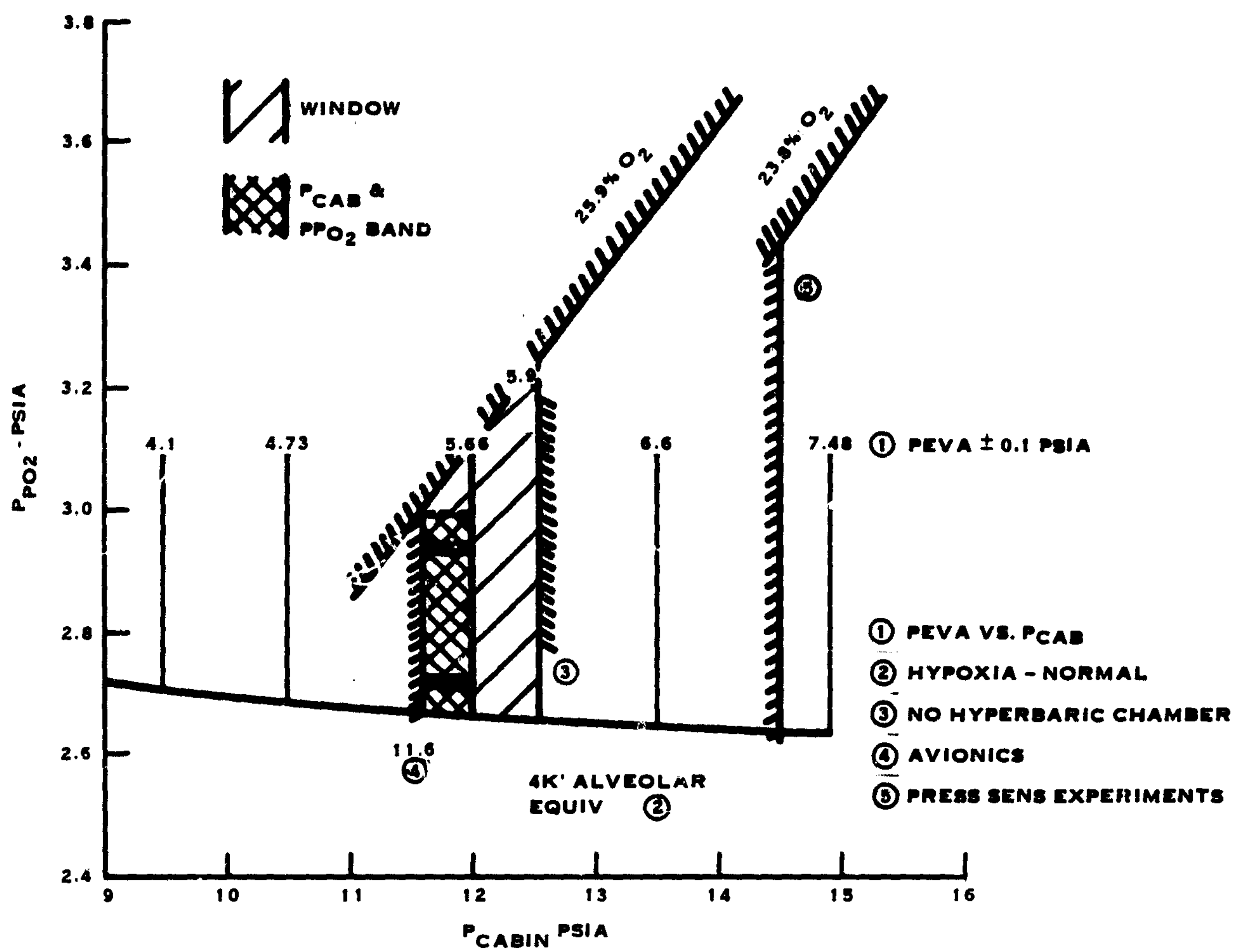
## ALLOWABLE WINDOW

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## TRADE STUDY - SELECTION OF OPTIMUM EVA PRESSURE

The allowable window permits EVA pressures from 5.66 to 5.9 psia. Selection of the optimum EVA pressure within the window involves the following conditions:

- High PEVA reduces suit mobility.
- High PEVA increases SOP impacts.
- Low PEVA requires longer initial $N_2$ washout.

The following tabulation shows the effects of the above considerations at the extremes of the window. An intermediate value of 5.78 psia represents the minimum PEVA which permits zero pure $O_2$ use prior to suit donning in support of "next day" EVA after 12 hours of exposure to cabin atmosphere at 11.8 psia nominal. This is consistent with STS-1 planning. This means that POS's are not required for "next day" EVA, and can be left stowed except for emergency use.

| | Nominal PEVA | | |
|---|---|---|---|
| | 5.66 | 5.78 | 5.90 psia |
| Estimated Suit Mobility Loss | | | |
| Elbow | 15 | 17 | 29% |
| Shoulder | 22 | 24 | 28 |
| Waist | 30 | 32 | 34 |
| Hip | 19 | 22 | 27 |
| Knee | 16 | 17 | 19 |
| Ankle | 8 | 9 | 10 |
| SOP Growth | 39 | 41 | 45% |
| One-Time Pure $O_2$ Use | | | |
| "Next Day" after breathing cabin $O_2/N_2$ for | | | |
| 12 hours | 0.2 | 0 | 0 hrs. |
| 16 hours | 0 | 0 | 0 |
| "Launch Day" | 1.2 | 1.1 | 1.0 hrs. |

## OPTIMUM EVA PRESSURE

5.78 ± 0.1 psia

- Eliminates all PGS use in support of "Next Day" EVA

- Reduces POS use in support of "Launch Day" EVA to 1.1 hours.

- Incurs minimal penalties over 5.66 psia PEVA.

    2% more SOP $O_2$ capacity

    1-3% more suit joint torque

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## SUMMARY OF MAJOR CONCLUSIONS

- The recommended optimum EVA pressure is 5.78 $\pm$ 0.1 psia.
- Recommended cabin pressure for operational flights with EVA is 11.8 $\pm$ 0.2 psia.
- The recommended combination of EVA and cabin pressure eliminates pre-breathe prior to EVA. However, the crewmembers bodies must be in approximate equilibration with cabin $N_2$ levels prior to EVA. This requires a one-time denitrogenation, taking 1.1 hours on pure $O_2$, to support the first EVA within several hours of launch; or reducing cabin pressure to 11.8 psia for 12 hours prior to the first EVA. Subsequent EVA's can be performed without additional denitrogenation from an 11.8 psia cabin using existing EMU donning and checkout procedures verified for STS-1.
- The recommended cabin pressure meets existing maximum and minimum $O_2$ levels, based on hypoxia and materials considerations.
- The Orbiter vehicle requires automatic cabin pressure control at 11.8 psia. This requires adding one total pressure regulator and shut-off valve to each of two parallel cabin pressurization subsystems.
- Payload flight assignment planning should continue to avoid inclusion of experiments that are sensitive to subatmospheric cabin pressure to flights with either planned EVA or where backup EVA is a possibility.
- Approximately 82% of EMU components require no change to support EVA at 5.78 psia.
- Significant EMU modifications consist of new gloves, enlarged SOP, re-worked suit joints, increased battery capacity and reset $O_2$ regulators. Minor modifications include revising flow restrictors, relief valves, and C&W set points, and strengthening select structural elements.
- The EMU Comparison - Impact Summary Comparison chart (overleaf) shows cabin conditions approved for OFT only. Modification of the EMU will permit improving cabin conditions for operational flights.

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# STUDY CONCLUSIONS

## OPTIMUM PRESSURES

- Cabin - 11.8 ± 0.2 psia
- EVA - 5.78 ± 0.1 psia

## ADVANTAGES

- Physiologically acceptable.
- No hyperbaric facility required.
- Cabin materials acceptable.
- Avionics OK with load management.
- Minimal impact to EMU LSS.
- EMU SSA joint concepts extendable.
- Minor changes to STE.

## IMPACTS

- 1-Time $N_2$ washout required.

  1.1 hours with pure $O_2$ for "Launch Day" EVA.
  12 hours with cabin $O_2/N_2$ for "Next Day" EVA.

- Cabin pressure control system modifications required.

  3rd regulator and shut-off valve.
  Reset $O_2/N_2$ controller set point.
  New C&W proms.

- Air-cooled avionics load management required.

  Shift some loads between avionics bays.
  Power down select cabin equipment to meet greater-than nominal heat loads.

- Screen carry-on experiments for function at 11.8 psia.
- Existing EMU glove marginal
- Revised SOP/approach required.

  May affect AAP, airlock and MMU.

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## EMU CONFIGURATION
## IMPACT SUMMARY COMPARISON

| EMU Configuration | Present | No Prebreathe |
|---|---|---|
| Use | OFT w/o prebreathe | OPS Flights |
| Acceptable for OPS Flights | No | Yes |
| $P_{CABIN}$ - psia | $\boxed{9.0}$ | 11.8 |
| $P_{EVA}$ - psia | 4.1 | 5.75 |
| Minimum Cabin $PPO_2$ - psia | $\boxed{2.46}$ | 2.66 |
| Maximum Cabin % $O_2$ | $\boxed{30}$ | 25.9 |
| Cabin Pressure Control | $\boxed{\text{Manual}}$ | Automatic |
| Avionics Power Down - kW | ~4 | ~2 |
| EMU Modifications Required | No | Yes |

☐ Approved For OFT Only and not acceptable for operational flights.

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## NEW TECHNOLOGY INITIATIVES

The following new technology initiates are recommended to facilitate implementation of a 5.78 psia suit.

Gloves - The EMU glove loses dexterity rapidly with increasing EVA pressure. Technology of the present glove does not appear adequate to support a workable glove at 5.78 psia. Hence a new technology iniative is recommended for developing gloves that are workable at 5.78 psig.

SOP - The SOP $O_2$ capacity requirement is 45% greater than the present SOP $O_2$ capacity to support normal EVA at 5.78 psia. A study initive is recommended to identify means for minimizing the impacts of the $O_2$ capacity increase to the AAP, airlock and MMU.

Joint Technology - Joint torque increases 9 to 37% at 5.78 psia. A joint technology extension initiative is recommended to reduce this impact.

Integrated Testing - The United States Manned Space Program has conducted all EVA at 4 psia. There is no widespread U.S. experience with higher EVA pressures. A new technology initiative is recommended to conduct an integrated unmanned and manned test program at the selected EVA pressure to gain assurance that issues of higher EVA pressures are well understood and to verify related procedures.

## NEW TECHNOLOGY

- Glove
- SOP Approach
- Joint Technology
- Integrated EVA Testing

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## APPENDIX - DISCUSSION MEMORANDUMS

The appendix consists of discussion memorandums prepared during the course of the Prebreathe Elimination Study to examine specific issues. Issues were developed with cooperation from cognizant people in relevant disciplines from NASA JSC and associated contractors. These memorandums comprise the information base for this study.

The appendix contains the following discussion memorandums:

| | |
|---|---|
| ECWS-PBE-01 | Physiological Aspects |
| ECWS-PBE-02 | Payload Issues |
| ECWS-PBE-03 | Cabin Pressure and Materials Issues |
| ECWS-PBE-04 | Consummables Analysis |
| ECWS-PBE-05 | Air-Cooled Avionics |
| ECWS-PBE-06 | EMU Impacts |

ECWS-PBE-01

# PREBREATHE ELIMINATION STUDY - PHYSIOLOGICAL ASPECTS

Richard C. Wilde
Engineering Manager, Advanced EVA Studies

November 1980

Hamilton Standard Division
United Technologies Corporation

Revised: March 1981

Revision B: June 1981

REPORT HIGHLIGHTS

Title: Prebreathe Elimination Study - Physiological Aspects

Object of Memo: Identify physiological limits for eliminating prebreathe with pure $O_2$ prior to EVA and identify broad operational procedures for staying within these limits. B

Findings and Conclusions:

1. Physiological considerations set the following limits on cabin and EVA pressures for eliminating prebreathe:

   Hypoxia - Lung alveolar $O_2$ partial pressure must not be less than the 4,000 foot altitude equivalent for normal operation or less than the 8,000 foot equivalent for emergency operation. A

   Ebullism - Total pressure must not be less than 0.91 psia.

   $O_2$ Toxicity - Cabin $O_2$ partial pressure should not exceed 3.8 psia, based on hematological considerations. EVA $O_2$ pressure should not exceed 8.0 psia for 3 EVA's. A

   Bends-limits - The ratio of cabin $N_2$ partial pressure to EVA total pressure should not exceed 1.6. A

   In addition, material flammability limits maximum cabin $O_2$ partial pressure, especially at lower cabin pressures. $O_2$ partial pressure is limited to 25.9% on the existing Orbiter. Most materials are acceptable for 30% $O_2$.

   The operating envelope for conducting EVA without prebreathe is shown in Figure A.

2. The minimum pressure for conducting EVA without any physiological, operational, or vehicle impacts is 7.25 psia. A

3. STS-1 pre-EVA checkout procedures include 20 minutes of pure $O_2$ exposure prior to dumping the airlock to vacuum. This appears adequate to support EVA down to 6.9 psia.

4. EVA at pressures below 7.25 psia require a one-time denitrogenation to washout dissolved gas present in body tissues at launch. Dissolved gas washout is a function of five variables: cabin total pressure, cabin $O_2$ partial pressure, EVA pressure, duration of exposure to reduced cabin pressure prior to EVA, and duration of exposure to pure $O_2$ prior to dumping the airlock. Present pre-EVA procedures fix two of these variables; exposure to reduced cabin pressure is at least 12 hours, and exposure to pure $O_2$ is approximately 20 minutes. A

   Figure B shows additional duration of pure $O_2$ exposure required to perform EVA over the entire range of EVA and cabin pressure shown in Figure A. Figure B shows that less than one hour of additional exposure to pure $O_2$ is required to support EVA down to 5.9 psia. A

Nature and Scope of Study:

Investigation is based on current physiology literature and STS OFT procedures. Procedures for conducting EVA on "launch" day and subsequent days were identified and evaluated using supersaturation R values found safe by USAF manned testing.

Advantages of Procedures:

1. All procedures eliminate prebreathe during actual suit donning, eliminating the most cumbersome aspect of present prebreathe procedures.

2. Developed equipment (POS and LEH) will support denitrogenation for "launch day" EVA. A

3. Minimal equipment use (up to 0.5 hours) is required to support denitrogenation for "next day" EVA. A

Disadvantages Caused by Procedures:

1. LEH may require conversion to closed loop operation to support "launch day" EVA.

2. Airlock materials may require certification for 30% $O_2$. A

3. All candidate denitrogenation procedures require verification using human testing before becoming operational procedures.

4. Other materials and equipment issues require further study.

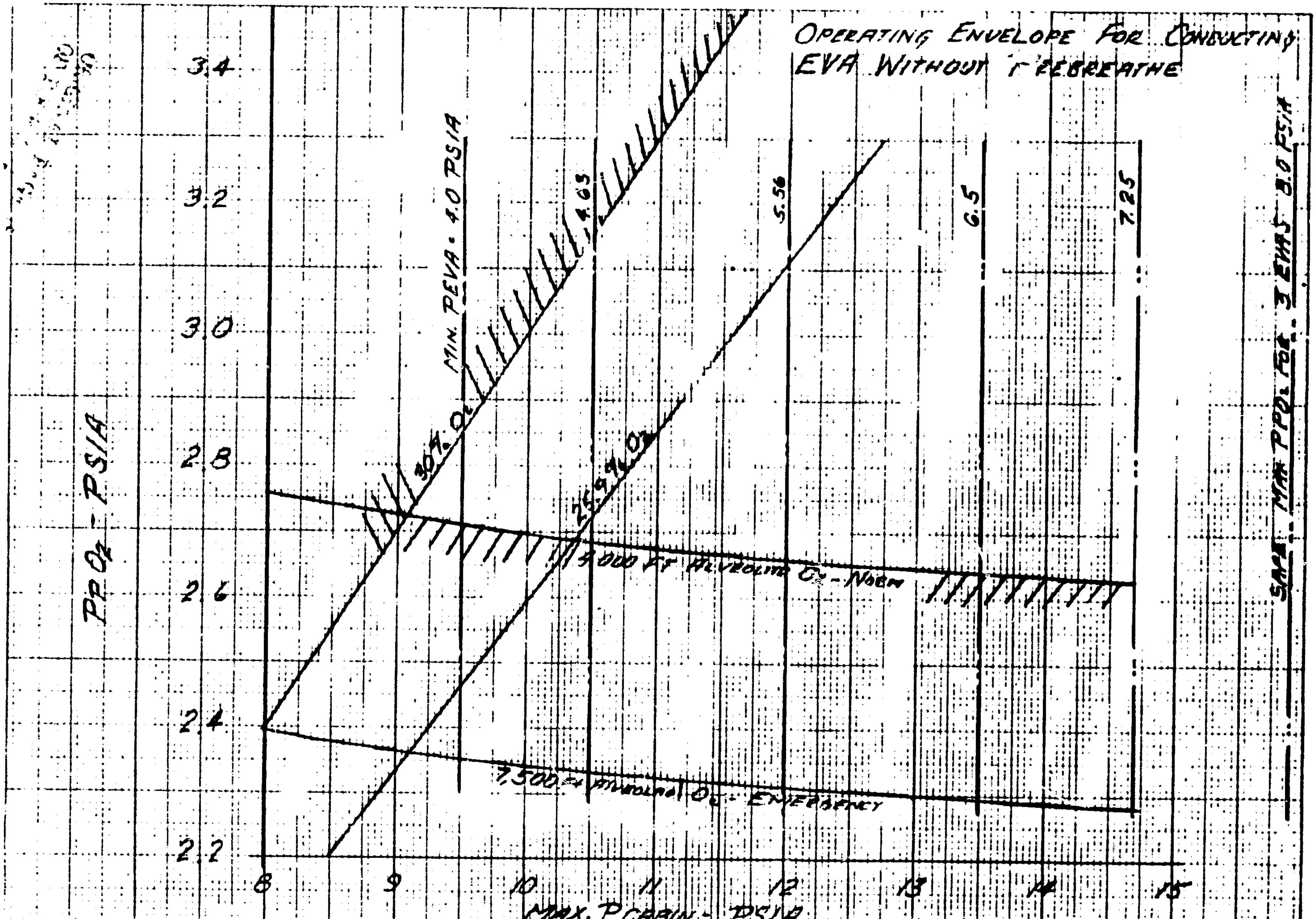


FIGURE - A

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8-16-81 REV.

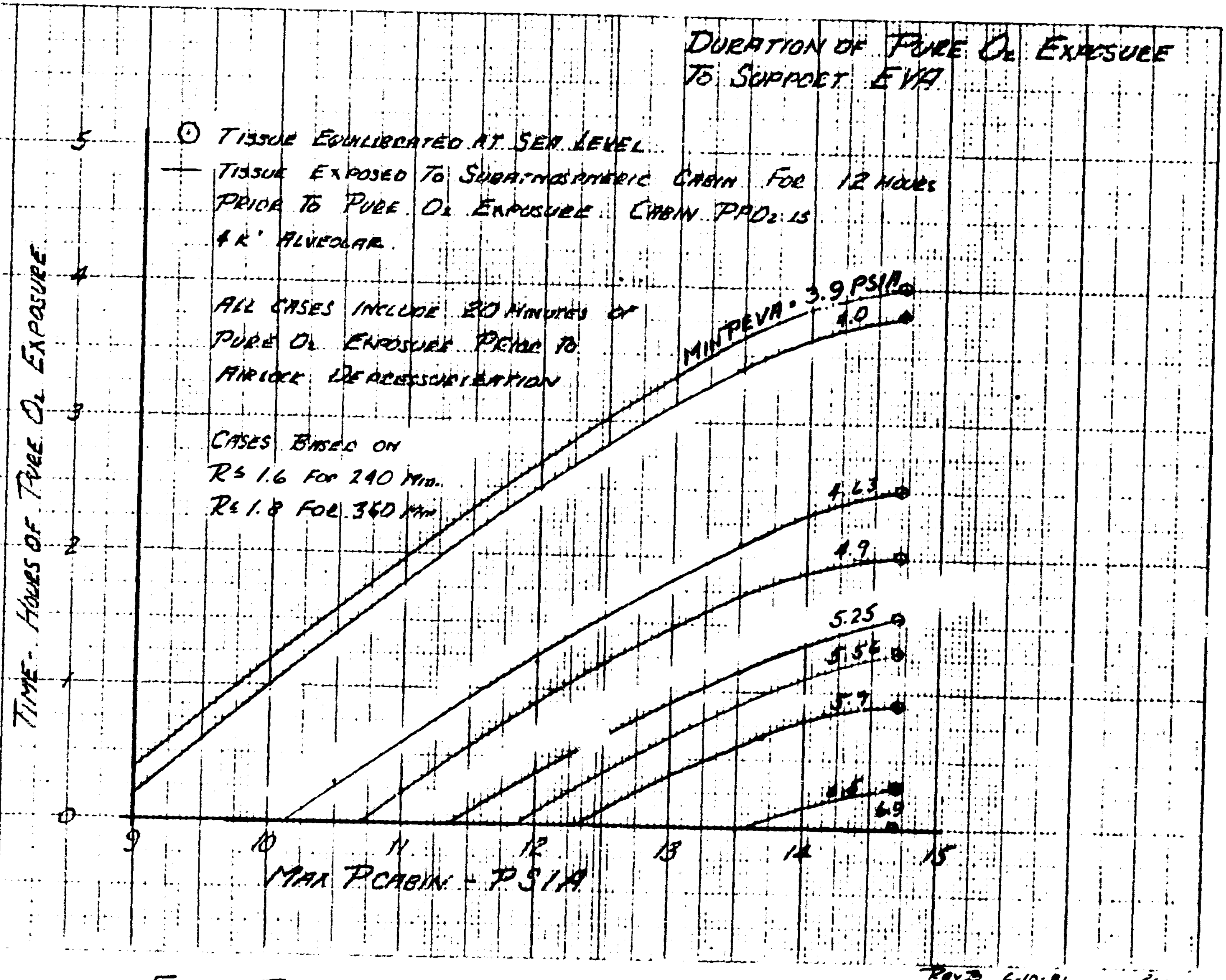


FIGURE-B

A-5

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DISCUSSION

## 1. Introduction

Prebreathe Elimination Study examines impacts of changing Orbiter cabin pressure and EMU EVA pressure to eliminate prebreathe prior to EVA. Because crew safety drives STS design and operation, physiological aspects are examined early in the study to define medically acceptable bounds within which equipment and operational changes can be considered.

This memo discusses medical and major operational aspects, namely:

- Physiological limits on cabin and EVA $O_2$ level
- For prebreathe elimination
  - Cabin to EVA pressure relationship
  - Nitrogen washout times from sea level launch to first EVA
- Intermediate airlock pressure to permit EMU donning without using the POS.
  - Airlock pressure and gas composition
  - Prebreathe times prior to EMU donning.

## 2. Physiological Limits on Cabin $O_2$ Level

Hypoxia sets the lower limits of cabin $O_2$ level. Alveolar $O_2$ level is the significant physiological parameter in setting hypoxic limits (References 3 and 5). Alveolar $O_2$ level is related to cabin gas composition by the following equation (References 3 and 5).

$$(1)\quad PAO_2 = FiO_2\,(PCab - PAH_2O) - PACO_2\left[FiO_2 + \frac{(1 - FiO_2)}{RER}\right]$$

where: $PAO_2$ = Alveolar oxygen pressure, torr
$FiO_2$ = Fraction of $O_2$ in breathing gas
$PCab$ = Cabin pressure, torr
$PAH_2O$ = Alveolar water vapor pressure
= 47 torr at body temperature
$PACO_2$ = Alveolar carbon dioxide pressure, torr
RER = respiratory exchange ratio. Assumed to be constant at 0.85 for this study (References 1, 3, and 5). Actual value varies up to 0.94 at 9 psi (Reference 4). Use of 0.85 biases $FiO_2$ values downward approximately 1.3% at 8 psi cabin pressure.

A more useful form of this equation permits plotting $FiO_2$ as a function of constant $PAO_2$ lines. Solving equation (1) explicitly for $FiO_2$ yields equation (2).

$$(2)\quad FiO_2 = \frac{PAO_2 + PACO_2/.85}{(PCab - 47) - (PACO_2/.85)(.85 - 1)}$$

The problem with this equation is that it has two unknowns, $FiO_2$ and $PACO_2$. The approach taken was to back calculate $PACO_2$ values from available data sources (References 2, 3, 4, and 5) and to plot them in Figure 1.

The most useful correlation of $PACO_2$ is with $PAO_2$ equivalent altitude, as Figure 1 shows. This plot permits selecting $PACO_2$ values for pure $O_2$ breathing gas, enriched $O_2$ cabin atmospheres and standard atmosphere composition.

Figure 1 shows some disagreement in $PACO_2$ between References 2 and 4 for standard atmosphere and between References 3 and 5 for enriched cabin atmosphere. However, a sensitivity analysis shows that $PACO_2$ variation affects $FiO_2$ values less than $\pm$ 0.5%. This study uses the Reference 5 correlation because it yields the most predictable $PACO_2$ values.

Figure 2 plots altitude equivalent $PAO_2$ lines against cabin pressure to yield $O_2$ partial pressure values. JSC Medical Science Division's position on hypoxic limits (which appears reasonable) is that $PAO_2$ should not fall below the equivalent of 4,000 feet for normal cabin operations and should remain above 8,000 feet for contingencies. At 4,000 feet, barely measurable effects to night vision occur. At 8,000 feet, more general effects on vision can be measured, and there is a pronounced effect on mental ability to learn new tasks (Reference 1). B

Medical Science Division's position on oxygen toxicity is that 3.8 psia $PPO_2$ exposure is safe for long duration exposure (Reference 5). This is a conservative limit based on hematological considerations. As a practical matter, material flammability is expected to limit maximum cabin $PPO_2$. Present cabin materials are evaluated for flammability up to 25.9% $O_2$. For cabin pressures below 14.7 psia, flammability limits may force maximum cabin $PPO_2$ to be less than 3.8 psia. A

3. Cabin to EVA Pressure Relationship

The relationship between cabin pressure and EVA pressure to avoid the bends is based on the pressure ratio of total dissolved gas in the tissues to EVA total pressure. For aviator's bends all dissolved gas contributes to bubble growth (Reference 9). The critical problem in bends occurs when bubble growth accelerates past a critical size within thisues that always contain tiny bubbles (micronuclei). Dissolved gasses within tissues are in equilibrium with inspired gas in amounts determined by both gas solubility within the tissues and degree of perfusion of tissues with blood (Reference 1).

Empirical studies of bends-susceptiblity represent total tissue dissolved gas pressure by inspired $N_2$ pressure (Reference 9), and hence express the ratio of total dissolved gas in the tissues to EVA total pressure as:

$$R = \frac{PIN_2}{PEVA}$$

$PIN_2$ is the inspired $N_2$ pressure = total pressure (-) $O_2$ partial pressure in the breathing gas (3.1 psia in a normal atmosphere).

PEVA = EVA total pressure.

It is generally accepted that safe levels of R depend on the half time of certain body tissues to release dissolved gasses. Representative tissues have gas release half times of 240 to 360 minutes. Based on experience with male flight crews, Medical Science Division considers R = 2.0 to be the upper acceptable limit of inspired $N_2$ to EVA pressure for people with demonstrated bends resistance. R = 1.6 is more conservative, and is expected to be safe for a larger segment of the population. R = 1.6 will be used in this study as a bends-limit to set the relationship between cabin pressure and EVA pressure (Reference 16). This is consistent with current USAF experience that rapid decompression from sea level to 18,000 feet is safe (R = 1.58). A B

Figure 3 shows a plot of minimum EVA pressure for bends avoidance without prebreathe as a function of cabin pressure, which is based on R = 1.6 and $PPO_2$ = 3.1 psia (21% $O_2$ in a normal atmosphere). This curve considers EVA down to a minimum of 4 psia, the present EMU operating pressure. Because prebreathe elimination is not served by reducing PEVA below present levels, this study considers PEVA at or above 4 psia, corresponding to a minimum cabin pressure of 9.5 psia. Note that this curve yields slightly lower EVA pressure for cabin pressures above 9.5 psia than the "traditional" values below obtained from the approximate relationship: A

(4) $PEVA = \frac{PCab\ N_2\ (Nom.)}{1.5}$ where $PCab\ N_2\ (Nom.) = PCab\ tot - 3.0$ (for $PPO_2$)

| PCab | PEVA (Eq. 4) | PEVA (Fig. 3) |
|---|---|---|
| 15 | 8 | 7.44 |
| 13.5 | 7 | 6.50 |
| 12 | 6 | 5.56 |
| 10.5 | 5 | 4.63 |
| 9.5 | 4.3 | 4.00 |

A

## 4. Dissolved Gas Washout Times

Tissue dissolved gas washout time for breathing $O_2$-$N_2$ cabin gas can be estimated by plotting the following equation (Reference 3).

(5) $PTDG = PI_oN_2 \pm [(PIN_2 - PI_oN_2)(1 - e^{-kt})]$

where PTDG = tissue dissolved gas pressure, psia
$PI_oN_2$ = initial inspired $N_2$ pressure, psia
k = .693/tissue half time, hours
t = time, hours

Figure 4 shows profiles of tissue dissolved gas washout while breathing cabin gas at reduced pressure. The curves are for 240 minute and 360 minute tissues, and are based on initial tissue dissolved gas pressure of 11.6 psia, which occurs at sea level locations such as KSC and WTR. For conservatism the cabin gas is assumed to contain $O_2$ at the 4,000 foot alveolar $O_2$ level, which is the acceptable minimum and which yields the maximum $PIN_2$.

The following table, using Figures 3 and 4, shows that for cabin pressures below 14.7 psia breathing cabin gas alone will never quite achieve safe tissue dissolved gas levels to support EVA at R = 1.6. A

| Max PCab tot (psia) | $PIN_2$ (psia) | Min PEVA (psia) | Max PTDG (psia) | Time (hours) |
|---|---|---|---|---|
| 14.7 | 11.60 | 7.25 | 11.6 | 0 |
| 13.5 | 10.86 | 6.50 | 10.4 | Never |
| 12 | 9.34 | 5.56 | 8.9 | Never |
| 10.5 | 7.81 | 4.63 | 7.4 | Never |
| 9.5 | 6.79 | 4.00 | 6.4 | Never |

B

A

The major reason is that equation 5 expresses an exponential decay. The intended washout uses the differential between $PIN_2$ and PTDG to drive PTDG toward $PIN_2$. However, PTDG will never reach $PIN_2$, because the driving potential approaches zero as the differential approaches zero.

Solving this problem requires driving PTDG down to $PIN_2$ prior to first EVA, and doing it quickly to support mission objectives. Tissues will renitrogenate to $PIN_2$ levels after the first EVA but will not exceed these levels. Thus no washout will be required for subsequent EVAs.

The remainder of this section considers candidate procedures for achieving initial tissue dissolved gas washout. R values are useful for evaluating candidate procedures. Recent USAF human testing has verified that some washout procedures are safe, i.e., incur acceptably low incidence of bends. Analysis of these procedures shows resulting R values of approximately 1.8 in 360 minute tissues and between 1.45 and 1.58 in 240 minute tissues (Reference 14). Hence, this study will consider candidate tissue dissolved gas washout procedures to be viable if they produce maximum R values of 1.8 in 360 minute tissues and 1.6 in 240 minute tissues. All these procedures will address initial reduction of PTDG to support EVA at a factor of 1.6 below $PIN_2$ (Reference 16). A

A point to be emphasized is that R values are used only to define and evaluate candidate washout procedures. Viable candidate procedures should then be verified safe by human testing before they become operational. Human testing is necessary, because individuals vary widely in their susceptibility to bends, owing to such factors as age, physical condition, amount of body fat, and presence of scar tissue. In addition, temperature, activity level, and time since last decompression affect a particular individual's susceptibility to bends (Reference 14). Moreover, published literature (References 1 and 10) indicates that women may be more bends-prone than men. The variability of individuals' responses to decompression makes it necessary to verify with human testing that candidate procedures are safe before committing any procedure to the operational baseline.

Two candidate tissue dissolved gas washout procedures are presented which appear to be safe for supporting EVA. Both procedures accelerate tissue dissolved gas washout towards equilibrium with the cabin, so that the suit can be donned with crewmembers breathing just cabin atmosphere. These procedures eliminate requirements to breathe pure $O_2$ during donning, thus significantly simplifying suit donning. The two procedure candidates are as follows and differ from one another in time to first EVA.

- To support "launch day" EVA, breathe pure $O_2$ for a prescribed time, during which the cabin pressure is reduced to a prescribed level. Then don the suit while breathing cabin gas and purge the suit with pure $O_2$ while performing final checkout.

- To support "next day" EVA, reduce the cabin pressure to a prescribed level. Breathe this atmosphere for a prescribed duration prior to donning the suit, then don the suit. Purge the suit with pure $O_2$ while performing final checkout.

The purpose of the "launch day" procedure is to washout tissue dissolved gas quickly so that EVA can be performed shortly after orbit insertion. The procedure calls first for breathing pure $O_2$ for a prescribed time to drive tissue dissolved gas level from sea level toward cabin inspired $N_2$ levels, the prescribed time being a function of cabin pressure on-orbit. The cabin pressure is reduced to on-orbit level during this time. Next, the crewmember breathes cabin gas for 1 hour while completing pre-EVA activity, preparing EVA equipment, entering the airlock, and donning the suit. The last step is to purge the suit with pure $O_2$ using the OPA, spending approximately 20 minutes while checking out the suit prior to dumping the airlock to vacuum. These steps and durations are consistent with STS-1 EVA operations planning (Reference 12).

The procedure can be performed two ways, depending on how soon EVA is planned after initial orbit insertion. If EVA is to occur almost immediately, crewmembers can begin washout during prelaunch and launch using the Launch-Entry Helmet (LEH). If EVA is planned for later in "launch day", crewmembers can start washout after post-orbit insertion tasks are complete, using the Portable Oxygen System (POS).

The POS is flight-ready to support tissue dissolved gas washout. The LEH is expected to require modification for closed loop operation. At present, the LEH operates open loop to support launch and entry, but could cause excessive cabin $O_2$ enrichment if used by both pilot and mission specialist for washout, especially at low cabin pressure. Bulkiness of $O_2$ hoses, required for closed loop operation, could encumber the pilot. These issues will be studied more fully later in the prebreathe elimination study.

Table 1 contains an analysis of "launch day" EVA procedures in terms of resulting R values for 360 and 240 minute tissues. The table shows the following:

- Washout durations range from zero to 3.7 hours, depending upon on-orbit cabin pressure and associated EVA pressure. A

- No pure $O_2$ washout is required prior to donning for a sea level cabin pressure to support EVA down to 7.25 psia. Twenty minutes in pure $O_2$ prior to dumping the airlock to vacuum appears to provide adequate margin to accommodate a slightly $N_2$-rich atmosphere which could result from controlling $PPO_2$ to the minimum (4,000 foot alveolar equivalent). A

- 240 minute tissues (R 1.6) set washout duration requirements down to cabin pressures of 12 psia. A

- 360 minute tissues (R 1.8) set washout duration at cabin pressures between 10.5 and 9.5 psia. A

It should be noted that body fast tissues will renitrogenate quickly to $PIN_2$ levels of the reduced pressure cabin during suit donning. For this reason whole body gas washout will not be as complete as if pure $O_2$ were breathed continously up to suit purge. The 9 and 10.5 psia cases in Table 1 reflect this for 240 minute tissues for which R is approximately 1.60. Without renitrogenation R would be approximately 1.56 and 1.36, respectively.

The purpose of the "next day" procedure is to assist tissue dissolved gas washout by breathing cabin gas at reduced pressure. This minimizes the requirement to use any pre-donning equipment. The procedure calls for reducing cabin pressure shortly after orbit insertion. The crew then eats, sleeps, and performs normal IV tasks until the next day. Following EVA equipment preparation and suit donning, the EVA crewmember purges the suit with pure $O_2$ and spends approximately 20 minutes performing EVA checkout prior to dumping the airlock to vacuum.

The procedure can be performed two ways, depending on how soon EVA is planned after reducing cabin pressure. One approach is to reduce cabin pressure approximately 24 hours prior to EVA. An alternative approach is to shorten that time to 12 hours, which is consistent with STS-1 mission planning (Reference 12), followed by a brief washout using pure $O_2$ (up to one half hour) to accelerate equilibration of body tissues with the cabin atmosphere.

Table 2A shows an analysis of the "next day" procedure performed after 24 hours at reduced cabin pressure. The table shows resulting R values calculated for 360 and 240 minute tissues. As expected, Table 2A shows resulting R's for all cabin pressures which are significantly below limiting values of 1.8 for 360 minute tissues. However, resulting R's for 240 minute tissues slightly exceed 1.6 for cabin pressures below 10.5 psia. JSC Medical's position is that these resulting R's are expected to be acceptable, pending verification by manned testing (Reference 17). <u>This procedure eliminates all requirements for tissue dissolved gas washout using pure $O_2$ prior to suit donning</u>.

Table 2B shows a similar analysis of the "next day" procedure using 12 hours of reduced cabin pressure prior to suit purge. Table 2B shows the following:

- A short tissue dissolved gas washout prior to suit donning using pure $O_2$ is required for cabin pressures below 13.5 psia to support bends-limit EVA. Washout durations using pure $O_2$ range up to 0.5 hours, depending on cabin pressure and associated EVA pressure.

- Zero duration is required to support bends-limit EVA from cabin pressure down to 13.5 psia. Spending 20 minutes in pure $O_2$ during EVA checkout appears to provide adequate protection.

- 240 minute tissues ($R \leq 1.6$) set duration of pure $O_2$ purge prior to suit donning for cabin pressures below 14.7 psia. Resulting R's for 360 minute tissues are all well below the 1.8 limit.

Conclusions drawn from considering tissue dissolved gas washout procedures (Tables 1, 2A, and 2B) are as follows:

- A one-time tissue dissolved gas washout is required prior to first EVA to support EVA at bends-limit values (per Figure 3) for all cabin pressures below sea level.

- No washout is required to support subsequent EVA's at bends-limit values.

- Breathing cabin gas alone is inadequate to support first EVA at sub-atmospheric cabin pressures. "Launch day" EVA can be supported at all cabin pressures by additional washout using pure $O_2$ prior to suit donning. Requirements for pure $O_2$ washout prior to suit donning can be reduced significantly or eliminated entirely by reducing cabin pressure and performing EVA on the "next day." A

- Candidate procedures have been identified to implement washout prior to first EVA. Flight-ready or modified equipment is expected to support pure $O_2$ washout for "launch day" EVA. Minimal equipment use is required to support washout for "next day" EVA. A

- All candidate procedures require verification by human testing before committing to operational baseline.

All candidate procedures have some drawbacks. All require analysis for effects on non-physiological aspects, e.g., equipment and materials impacts and operational constraints. These will be considered later in this study.

5. <u>EVA Pressure Limits</u>

In addition to the bends limits shown in Figure 3, other physiological constraints on EVA pressure are:

- Ebullism -

  Pressure must be kept above 0.91 psia to prevent body fluids from boiling at 98.6°F (Reference 5).

- Hypoxia -

  $O_2$ level must be kept above the 4,000 foot altitude alveolar equivalent as shown in Figure 5 (Reference 5).

- Oxygen toxicity -

  Exposure to pure $O_2$ at up to 8 psi is not expected to be a problem for 3 EVA's per mission (Reference 6). However, for more than 3 EVA's per mission, there is evidence that intermittent exposure to pure $O_2$ at 8 psia may be harmful (Reference 7).

- Bends Protection During EVA Contingency -

  Present STS practice requires 3 to 4 hours of pure $O_2$ prebreathing to protect against effects of decompression from 14.7 psia in the cabin to 4.0 to 4.2 psia pure $O_2$ EVA pressure, which results in a mean R value of approximately 1.6 for 240 minute tissues. The EMU secondary $O_2$ supply will maintain pure $O_2$ pressure at 3.25 to 3.55 psia for 30 minutes, resulting in a mean R value of approximately 1.9. If an emergency extends beyond 15 to 20 minutes, the risk of experiencing bends exists. A

  In considering EVA pressure up to 7.25 psia it may be advantageous from equipment or other non-physiological viewpoints to provide pure $O_2$ emergency EVA pressurization at close to hypoxia limit levels as shown in Figure 5 for 4,000' $PAO_2$. This would increase the risk of bends A during the last 10 to 15 minutes of an emergency by allowing R for 240 minute tissues to exceed 1.9. The amount by which R exceeds 1.9 can increase dramatically as normal EVA pressure rises towards 7.25 psia as follows: A

| PEVA Normal (psia) | 4,000 ft. $PAO_2$ PEVA Emergency (psia) | *PDTG (psia) | R (240 Min.) (PTDG/PEVA Emergency) | |
|---|---|---|---|---|
| 4.0 | 3.09 | 6.48 | 2.09 | |
| 4.63 | 3.01 | 7.43 | 2.47 | A |
| 5.56 | 2.90 | 8.85 | 3.05 | |
| 6.5 | 2.83 | 10.28 | 3.63 | |
| 7.25 | 2.79 | 11.39 | 4.08 | |

This example clearly shows that bends protection should be considered in establishing acceptable emergency EVA pressure levels as we contemplate EVA normal pressure levels above 4 psia. This is a new question for which medical guidance is presently not available. Dave Horrigan has agreed to think about this question and share his thoughts with me (Reference 8).

One potential approach is to retain the present risk of bends occurrence by not exceeding a value of R = 1.9. This would produce the following relationship between normal and emergency EVA pressures.

| PEVA Normal (psia) | *PTDG (psia) | R = 1.9 PEVA Emergency (psia) | |
|---|---|---|---|
| 4.0 | 6.48 | 3.4 | |
| 4.63 | 7.43 | 3.9 | A |
| 5.56 | 8.85 | 4.7 | |
| 6.5 | 10.28 | 5.4 | |
| 7.25 | 11.39 | 6.0 | |

*Max. values for 240 minute tissues resulting from Table 2A procedure. A

## 6. Intermediate Airlock Pressure

At this point in the study we recognize the possibility that it may be disadvantageous for equipment or Orbiter reasons to adjust EVA and/or cabin pressures sufficiently to eliminate prebreathe altogether. A potential work-around would be to set the airlock at an intermediate pressure from which it would be safe to perform EVA, and to prebreathe before entering the airlock.

Prebreathe would then be terminated within the airlock prior to donning the suit. This work-around allows breathing the airlock atmosphere during suit donning and eliminates use of the POS and breather hose/mouthpiece during donning. Relieving this requirement would simplify EMU donning significantly.

This work-around is similar to candidate procedures for "launch day" EVA in which washout with pure $O_2$ in interrupted by breathing reduced pressure airlock atmosphere. The intermediate airlock pressure case confines reduced pressure to the airlock. The "launch day" procedure candidates use reduced pressure in both cabin and airlock. As in the "launch day" case, fast tissues will renitrogenate to $PIN_2$ levels present in the airlock atmosphere.

Evaluation of the intermediate airlock pressure work-around uses STS-1 mission planning as follows:

- "Launch day" EVA completes cabin depressurization 8 hours after launch (Reference 12). EVA should start shortly thereafter or else the day will get too long. Hence this evaluation considers initial PTDG to be sea level, regardless of the actual on-orbit cabin pressure level.

- "Next day" EVA checkout occurs approximately 12.75 hours after completion of cabin pressure reduction (Reference 12). This evaluation allows 12 hours as the maximum time for PTDG to approach $PIN_2$ following cabin pressure reduction.

- EVA equipment preparation, donning, and checkout take just under 1 hour, with prep taking 25 minutes (Reference 13). Using 20 minutes for EVA checkout leaves approximately 10 - 15 minutes to don the pressure garment in the airlock, breathing airlock gas. This time is long enough to renitrogenate fast tissues up to airlock $PIN_2$ levels (Reference 1), but may not be long enough to continue washout of slow tissues (Reference 9). Hence this evaluation assumes renitrogenation of fast tissues up to airlock $PIN_2$, but omits any washout from slow tissues during this time.

The work-around procedure for using intermediate airlock pressure is to prebreathe for a prescribed duration, depending on cabin pressure and EVA pressure, as shown in Figure 6. Complete EVA equipment prep before terminating prebreathe, enter the airlock, and close the inner hatch.

The intermediate airlock total pressure requires $N_2$ partial pressure to be 1.6 times PEVA plus a minimum $O_2$ partial pressure equivalent to 4k' alveolar. Thus the airlock pressure to support 4 psia EVA has 6.4 psi $N_2$ plus 2.7 psi $O_2$ for a total of 9.1 psia. To achieve this the airlock is depressurized briefly to 7.8 psia, followed by repressurization with pure $O_2$ up to 9.1 psia, a process requiring approximately 1.125 lb of $O_2$. Four psi EVA requires the greatest amount of $O_2$ to repressurize the airlock, hence results in the highest $O_2$ percentage in the airlock.

Terminate prebreathe once the intermediate airlock pressure is achieved. Don the pressure garment assembly while breathing the airlock atmosphere. Then purge the suit with pure $O_2$ and perform EVA checkout for approximately 20 minutes prior to dumping the airlock to vacuum.

Table 3 shows prebreathe times and resulting R values for all cabin and EVA pressures considered in this study, as well as airlock intermediate pressures and $O_2$ percentages. As expected, prebreathe times range from 0 to 3.8 hours depending on the selected combination of cabin and EVA pressure. At the lowest EVA pressure, 360 minute tissues determine prebreathe time. At higher EVA pressures the 240 minute tissues determine prebreathe time. Table 3 also shows that using reduced $N_2$ pressure in the airlock would allow significant reduction in prebreathe times if cabin pressure is lowered several psi or if EVA pressure is raised from one to two psi.

Figure 6 is a plot of Table 3 data showing prebreathe durations required to support the entire range of EVA pressures from all cabin pressures considered in this study.

## REFERENCES


1. "Medical Science Position on Space Cabin and Suit Atmospheres," Position paper by NASA JSC/SD, May 1980.

2. ARDC Model Atmosphere - 1962, Table published by the Garrett Corporation.

3. "Denitrogenation Curves," Memo to D. J. Horrigan Jr. (SD) from Joseph P. Kerwin (CB), dated 11-9-79.

4. U.S. Naval Flight Surgeon's Manual, Naval Aerospace Medical Institute, 2nd edition, Washington, DC, U.S. Government Printing Office, 1978.

5. NASA Reference Publication 1045, "The Physiological Basis for Spacecraft Environmental Limits," J. M. Waligora, Coordinator, 1978.

6. Conversation with Mr. James Waligora and Mr. David Horrigan at NASA JSC on 11-3-80.

7. NADC-74241-40, "Physiological Responses to Intermittent Oxygen and Exercise Exposures," E. Hendler, NADC, Warminster, PA, 1974.

8. Telecon with Mr. David Horrigan of NASA JSC on 11-24-80.

9. Memo to Mr. Manuel Rodriguez Jr. from Mr. James Waligora, NASA JSC/SD3, "Comments on Hamilton Standard Memo ECWS-PBE-01 (Preliminary)", dated 12-18-80.

10. Bassett, Bruce E. Lt. Col., USAF, Crew Protection Branch, USAF School of Aerospace Medicine, Brooks AFB, Texas 78235, "Twelve Year Survey of the Susceptibility of Women to Altitude Decompression Sickness," Preprint of paper presented at Aerospace Medical Conference, Anaheim, CA, May 1980.

11. Telecon with Mr. David Horrigan of NASA JSC on 1-20-81.

12. STS-1 Flight Data File EVA Operations Book, JSC-16751, Basic, January 2, 1981.

13. STS-1 Flight Data File EVA Checklist, JSC-12813, Preliminary, Revision B, August 15, 1980.

14. Report of Trip to Brooks AFB and NASA JSC 1-26 to 1-20-81, R. Wilde, Hamilton Standard, dated February 4, 1981.

15. NASA SP-117, "Space-Cabin Atmospheres, Part III, Physiological Factors of Inert Gasses," Emanuel M. Roth, M.D., NBSA Office of Technology Utilization, Washington, DC, 1967.

16. Report of Trip to NASA JSC, 3-23 to 3-28-81, R. Wilde, Hamilton Standard, April 2, 1981.

17. Telecon with Mr. David Horrigan of NASA JSC on 4-10-81. A

## TABLE 1

### Launch Day Tissue Dissolved Gas Washout Procedure

Procedure consists of:

- Washout with pure $O_2$ for prescribed duration while reducing PCab to on-orbit level.
- Breathe cabin atm. for 1 hour. Perform EVA equipment prep and suit donning.
- Purge suit with pure $O_2$ and spend 20 minutes performing EVA checkout prior to dumping the airlock to vacuum.

| Max PCab | 4k' Equiv. $PPO_2$ | Min PEVA | Pure $O_2$ Washout | Resulting R Values 360 Min. $R = \frac{PTDG}{PEVA}$ | 240 Min. $R = \frac{PTDG}{PEVA}$ |
|---|---|---|---|---|---|
| psia | | psia | time, hours | | |
| 14.7 | 2.63 | 7.25 | 0 | 1.60 | 1.57 |
| 13.5 | 2.64 | 6.5 | 0.3 | 1.65 | 1.60 |
| 12 | 2.66 | 5.56 | 1.2 | 1.73 | 1.60 |
| 10.5 | 2.69 | 4.63 | 2.4 | 1.80 | 1.59 |
| 9.5 | 2.71 | 4.0 | 4.7 | 1.80 | 1.60 |

# TABLE 2A

## Next Day Tissue Dissolved Gas Washout Procedure
## (24 hours prior to EVA)

Procedure consists of:

- Reduce cabin pressure for 24 hours prior to EVA checkout.
- Breathe cabin gas for 24 hours. Complete EVA prep ans suit donning.
- Purge suit with pure $O_2$ and spend 20 minutes performing EVA checkout prior to dumping the airlock to vacuum.

| Max PCab | 4 k' Equiv. $PPO_2$ | Min PEVA | Cabin Depress. Duration | Resulting R Values 360 Min. R = PTDG/PEVA | 240 Min. R = PTDG/PEVA |
|---|---|---|---|---|---|
| psia | | psia | hours | | |
| 14.7 | 2.63 | 7.25 | 24 | 1.60 | 1.57 |
| 13.5 | 2.64 | 6.5 | 24 | 1.62 | 1.58 |
| 12 | 2.66 | 5.56 | 24 | 1.64 | 1.59 |
| 10.5 | 2.69 | 4.63 | 24 | 1.67 | 1.60 |
| 9.5 | 2.72 | .0 | 24 | 1.71 | 1.62 |

TABLE 2B

Next Day Tissue Dissolved Gas Washout Procedure
(12 hours prior to EVA)

Procedure consists of:

- Reduce cabin pressure for 12 hours prior to EVA checkout.
- Breathe pure $O_2$ for minimum duration to accelerate equilibration of body tissues with reduced pressure cabin atmosphere.
- Breathe cabin gas for 1 hour duration. Perform EVA prep and suit donning.
- Purge suit with pure $O_2$ and spend 20 minutes performing EVA checkout prior to dumping the airlock to vacuum.

| Max PCab psia | Min PEVA psia | Cabin Depress. Duration hours | Pure $O_2$ Washout Duration hours | Resulting R Values 360 Min. $R = \frac{PTDG}{PEVA}$ | 240 Min. $R = \frac{PTDG}{PEVA}$ |
|---|---|---|---|---|---|
| 14.7 | 7.25 | 12 | 0 | 1.60 | 1.57 |
| 13.5 | 6.5 | 12 | 0.2 | 1.64 | 1.59 |
| 12 | 5.56 | 12 | 0.2 | 1.66 | 1.59 |
| 10.5 | 4.63 | 12 | 0.3 | 1.74 | 1.59 |
| 9.5 | 4.0 | 12 | 0.5 | 1.78 | 1.60 |

**TABLE 3**

**Intermediate Airlock Pressure**

Procedure consists of:

- Establish orbital cabin pressure level.
- To support "launch day" EVA prebreathe pure $O_2$ based on 14.7 psi cabin. For "next day" EVA breathe cabin atmosphere for 12 hours, then prebreathe pure $O_2$ based on on-orbit cabin pressure.
- Complete EVA prep, enter airlock, and set airlock intermediate pressure ($PPN_2$ = 1.5 PEVA, $PPO_2$ = 4k' alveolar)
- Terminate prebreathe; don suit.
- Purge suit with pure $O_2$ and spend 20 minutes performing EVA checkout prior to dumping the airlock to vacuum.

| Min PEVA (psia) | $PN_2$ A/L (psia) | $PO_2$ A/L (psia) | PTOT A/L (psia) | $FiO_2$ A/L (%) | Max PCab (psia) | Prebreathe Time (hours) | Resulting R PTDG/PEVA (240 min) | (360 min) |
|---|---|---|---|---|---|---|---|---|
| 4.0 | 6.4 | 2.7 | 9.1 | 30 | 9.5 | 0.6 | 1.58 | 1.80 |
| | | | | | 10.5 | 1.4 | 1.53 | 1.80 |
| | | | | | 12 | 2.5 | 1.51 | 1.80 |
| | | | | | 13.5 | 3.4 | 1.51 | 1.80 |
| | | | | | 14.7 | 3.8 | 1.51 | 1.80 |
| 4.63 | 7.1 | 2.7 | 9.8 | 28 | 9.5 | 0 | 1.51 | 1.66 |
| | | | | | 10.5 | 0.3 | 1.59 | 1.54 |
| | | | | | 12 | 1.2 | 1.51 | 1.80 |
| | | | | | 13.5 | 2.1 | 1.57 | 1.80 |
| | | | | | 14.7 | 2.5 | 1.54 | 1.80 |
| 5.56 | 8.9 | 2.7 | 11.6 | 23 | 10.5 | 0 | 1.51 | 1.54 |
| | | | | | 12 | 0.1 | 1.60 | 1.71 |
| | | | | | 13.5 | 0.9 | 1.60 | 1.72 |
| | | | | | 14.7 | 1.3 | 1.59 | 1.74 |
| 6.5 | 10.4 | 2.7 | 13.1 | 21 | 13.5 | 0 | 1.58 | 1.64 |
| | | | | | 14.7 | 0.3 | 1.60 | 1.65 |

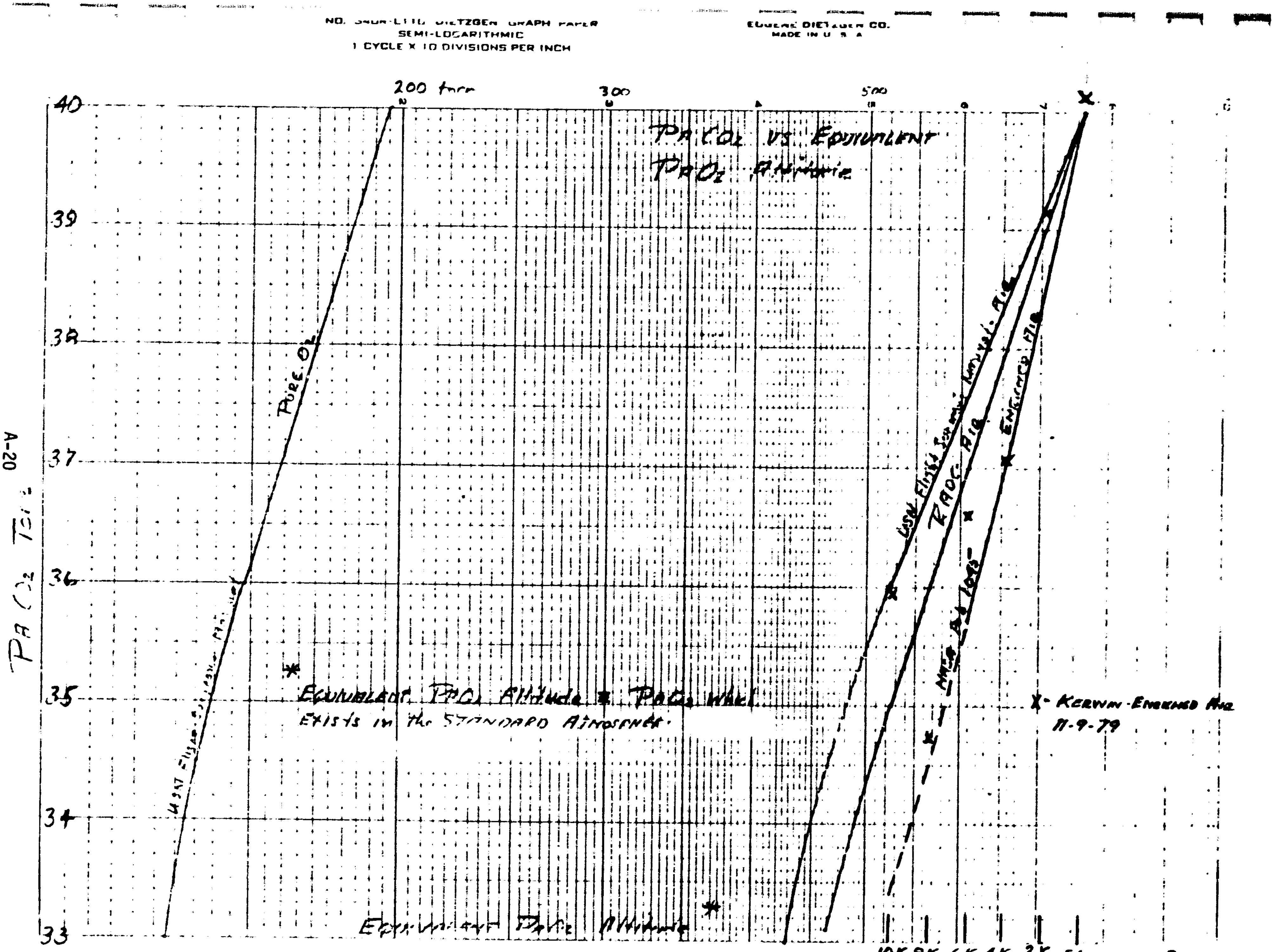
NO. 340R-L110 DIETZGEN GRAPH PAPER
SEMI-LOGARITHMIC
1 CYCLE X 10 DIVISIONS PER INCH
EUGENE DIETZGEN CO.
MADE IN U. S. A.
200 torr
300
500
PaCO2 vs Equivalent
PAO2 Altitude
Pure O2
USN Flight Surgeon Manual
USN Flight Surgeon Manual Air
RAOC Air
Engineered Air
NASA BA 1093
Equivalent PAO2 Altitude * PAO2 which
Exists in the Standard Atmosphere.
X - Kerwin - Engineered Air
11-9-79
Equivalent PAO2 Altitude
10K 8K 6K 4K 2K SL
40
39
38
37
36
35
34
33
PA CO2 Torr
FW

Figure 1.

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20 X 20 PER INCH

DIETZGEN CORPORATION
MADE IN U.S.A.

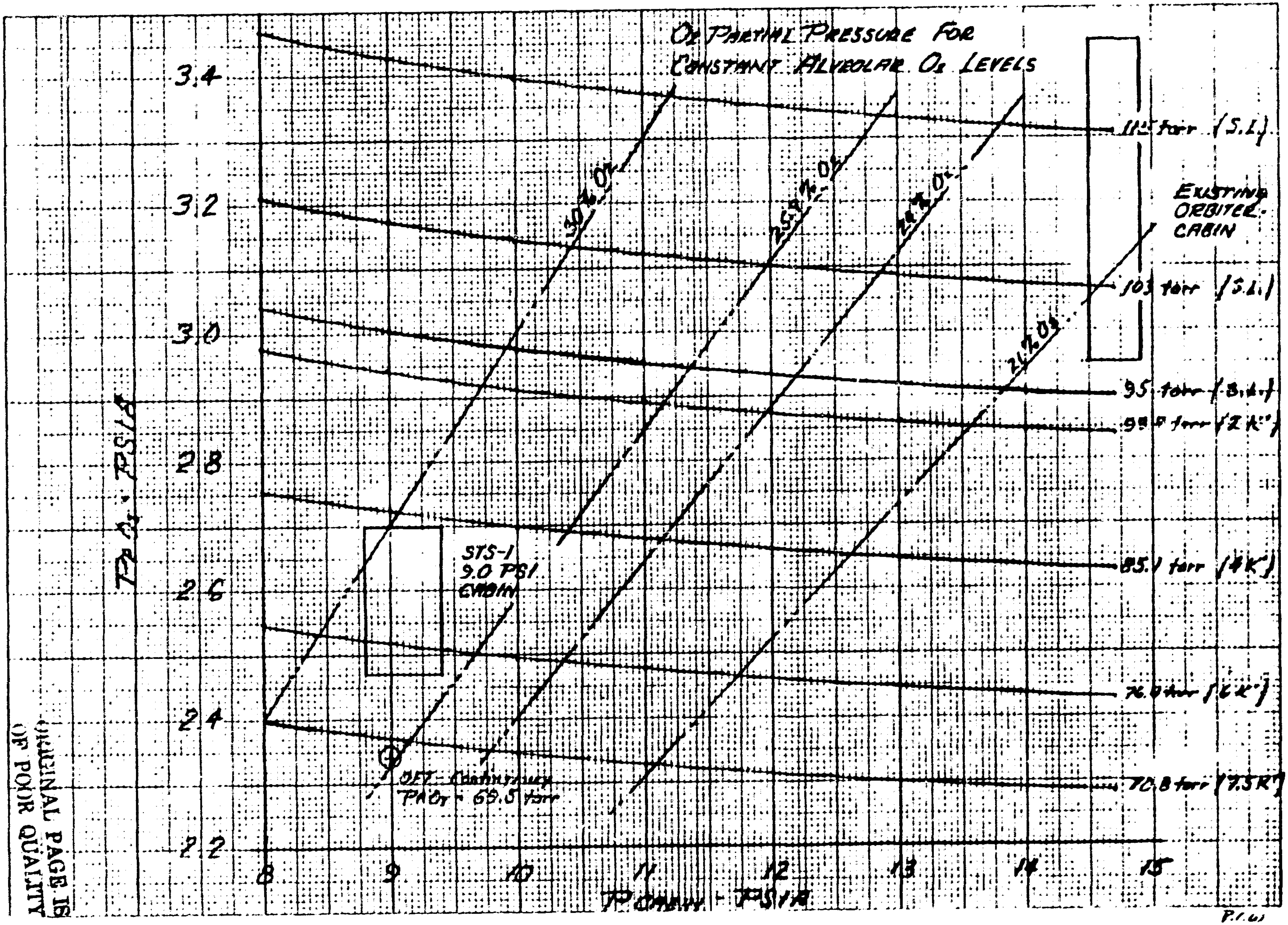


Figure 2

P.C.G.
11-17-80

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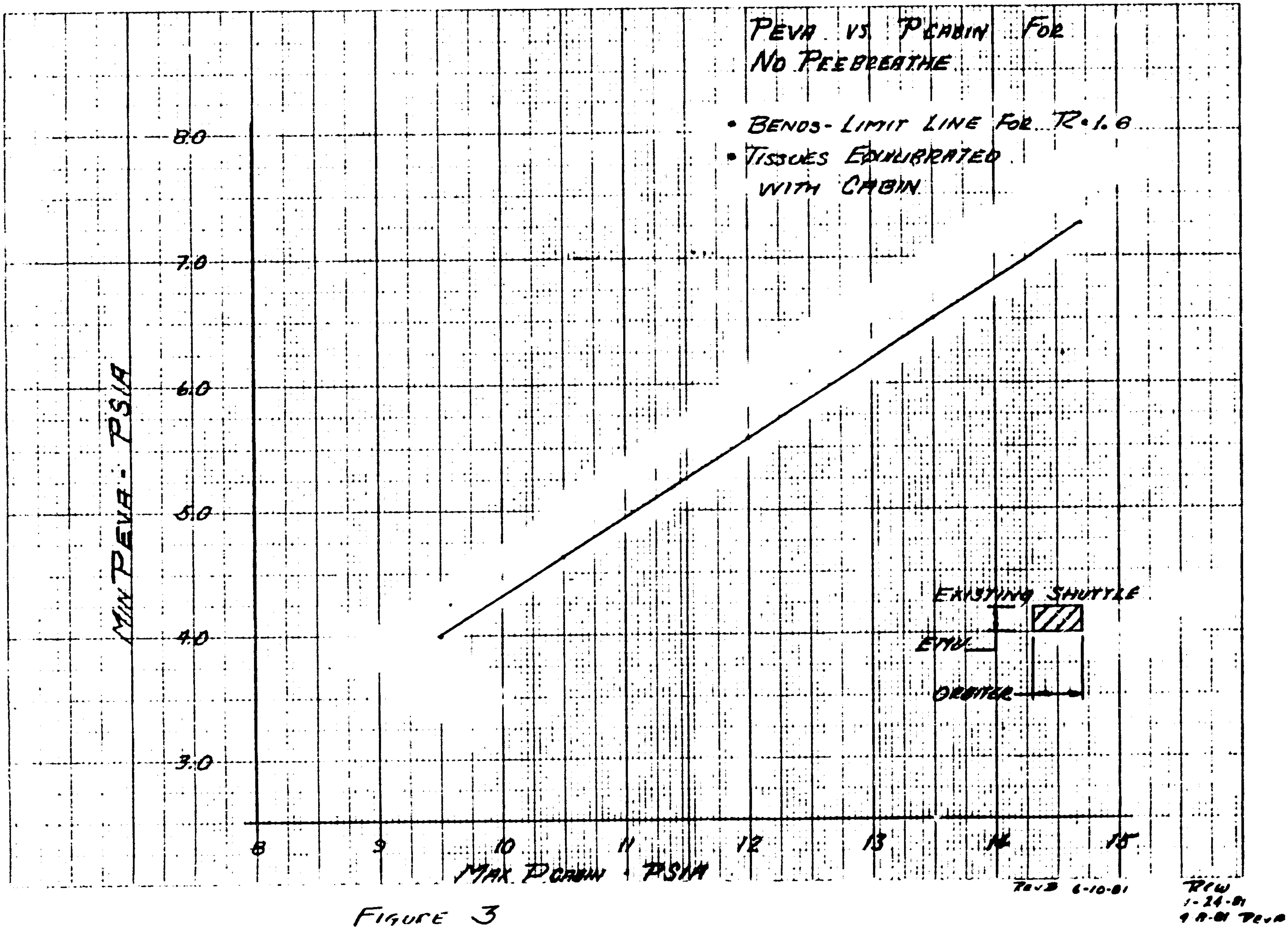
OF POOR QUALITY



PEVA VS PCABIN FOR
NO PREBREATHE
• BENDS - LIMIT LINE FOR R = 1.6
• TISSUES EQUILIBRATED WITH CABIN
8.0
7.0
6.0
5.0
4.0
3.0
MIN PEVA - PSIA
8
9
10
11
12
13
14
15
MAX PCABIN - PSIA
EXISTING SHUTTLE
EMU
ORBITER
REV B 6-10-81
RFW
1-24-81
4-8-81 REV A


FIGURE 3

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20 X 20 PER INCH

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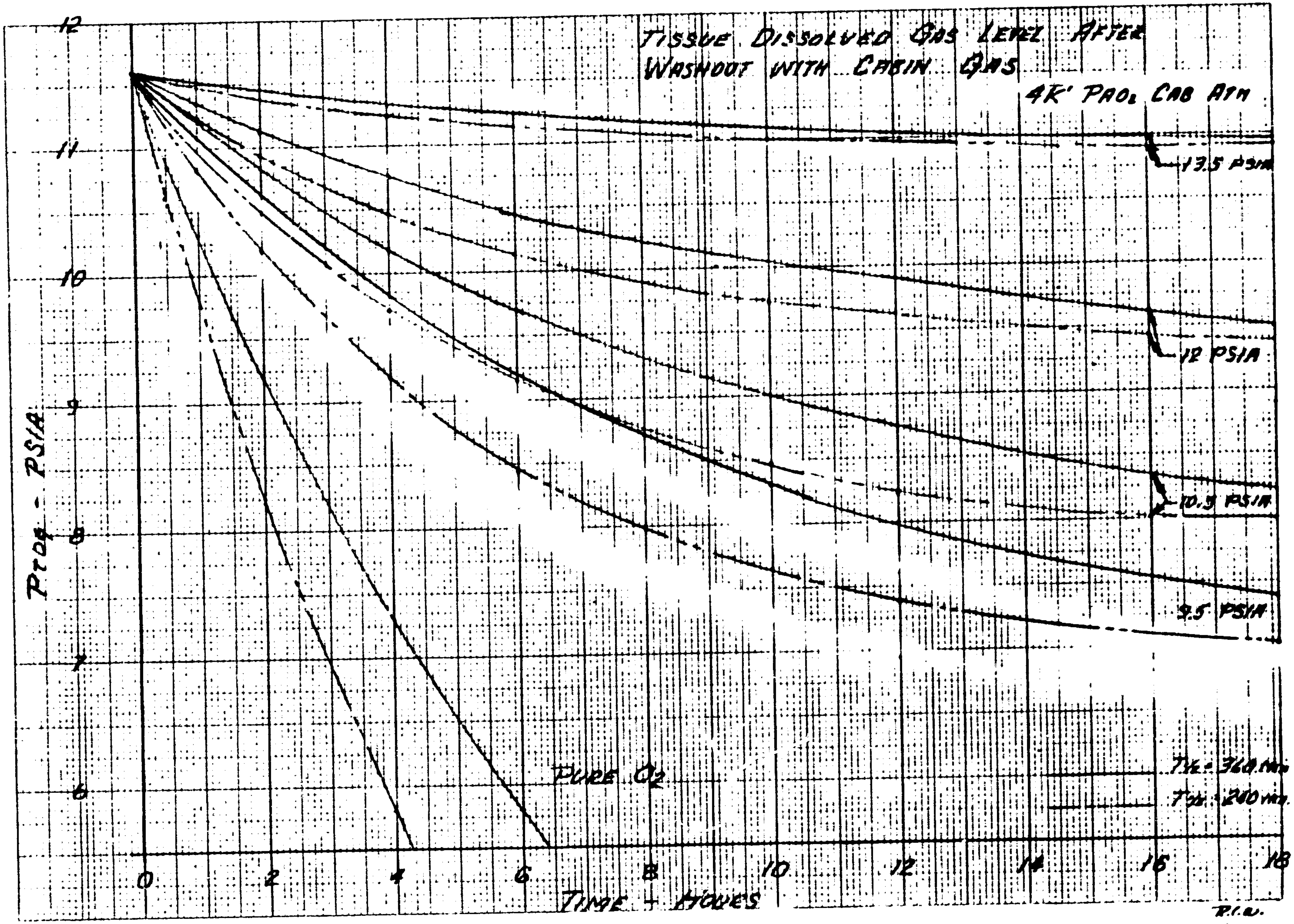
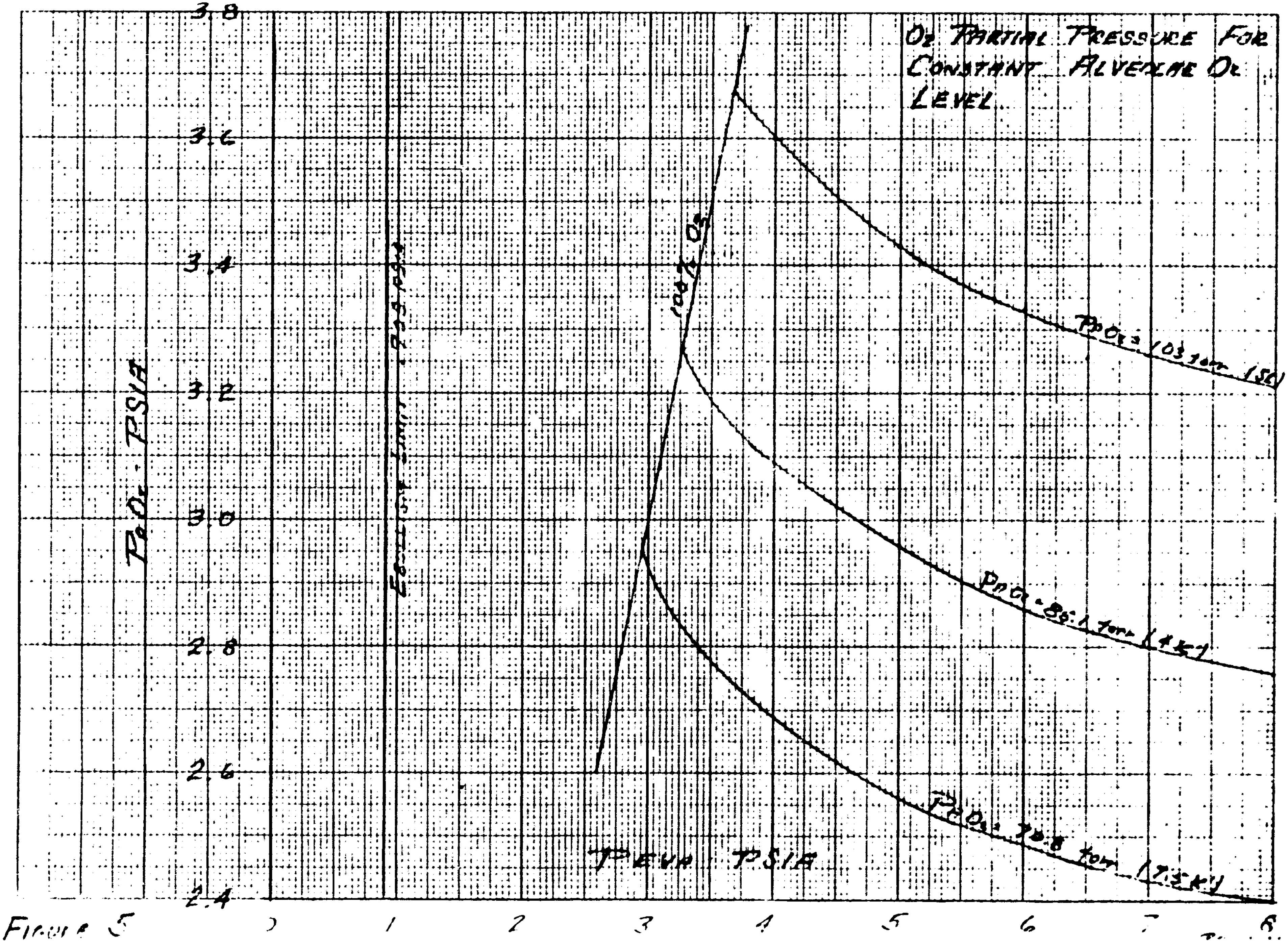



FIGURE 4

R.L.W.
1-30-81
REV. A 4-16-81


O2 PARTIAL PRESSURE FOR
CONSTANT ALVEOLAR O2
LEVEL
PAO2 = 103 torr (SL)
PAO2 = 86.1 torr
PAO2 = 70.8 torr
100% O2
PO2 - PSIA
PSIA
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
0
1
2
3
4
5
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7
8

FIGURE 5

DIETZGEN GRAPH PAPER
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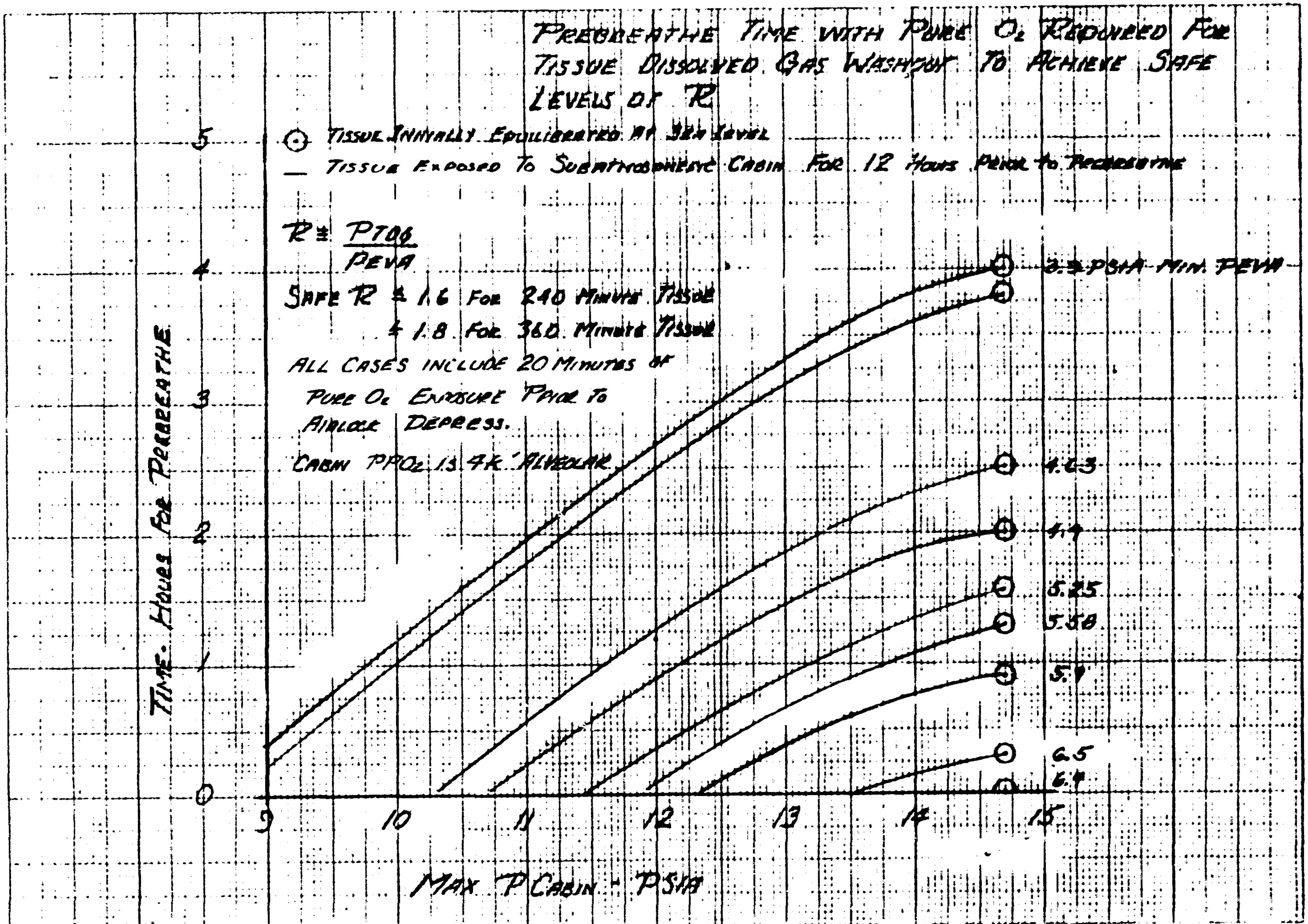


FIGURE 6

ECWS-PBE-02

# PREBREATHE ELIMINATION STUDY - PAYLOAD ISSUES

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Engineering Manager, Advanced EVA Studies

July 1981

Hamilton Standard Division
United Technologies Corporation

MEMO HIGHLIGHTS

Title: Prebreathe Elimination Study - Payload Issues

Object of Memo: Identify conflicting requirements between payloads sensitive to cabin pressure and payloads using EVA, and identify approaches to minimize these conflicts.

Nature and Scope of Study:

This investigation is based on current flight assignment planning and payload integration planning. Specific information was obtained from published literature and from interviews with NASA JSC personnel in the Payload Integration Office, Safety and Life Sciences areas. The investigation defines conflicting requirements of EVA and pressure-sensitive payloads and identifies approaches for minimizing the conflicts.

Findings and Conclusions:

1. Conflict between EVA support and payload requirements arises from the desire to reduce cabin pressure to support EVA without requiring pure $O_2$ prebreathe. Reduced cabin pressure may adversely affect certain classes of payloads.

2. Classes of pressure - sensitive payloads are Spacelab manned modules and carry-on experiments. Individual payloads within these classes may exhibit two types of pressure sensitivity:

   - Material flammability - Cabin payload materials are rated for 25.9% $O_2$ partial pressure maximum. This partial pressure may be exceeded at cabin pressures below 11.5 psia and could go to 33% at a minimum cabin pressure of 9.5 psia. Refer to Figure 1.

   - Experiment function - Certain experiments, as exemplified by life science cardio-pulmonary and hematology, are sensitive to total pressure and $O_2$ concentration, respectively. Also, cooling provisions may be inadequate for some heat-generating experiments.

3. Other payload classes consisting of satellites, structures, and experiment pallets are not sensitive to cabin pressure.

4. The minimum cabin pressure to support EVA without prebreathe is 9.5 psia. Refer to Figure 2.

5. STS Program planning recognizes three types of EVA:

   - Planned - EVA is the baseline mode for meeting payload mission objectives. Space Telescope is the only such payload so designed to date. Future payloads, such as Power System and SOC, are expected to use planned EVA. Further in the future construction and satellite service are expected to use planned EVA increasingly.

   - Backup - EVA is the backup mode for meeting payload objectives. IUS erector is the only payload so designed to date. PAM-D payload is being concepted to use backup EVA. Future satellite checkout and deployment are expected to make increasing use of backup EVA.

- Contingency - EVA is the contingency mode for supporting safe return of Orbiter to Earth. Presently planned-for contingencies include tile repair and payload-bay door closure. There is no conflict between payloads and contingency EVA because safe return overrides payload data and equipment survival considerations.

6. Recent flight assignment planning, consisting of 79 flights through September 1986, supports reduction of conflict by not combining 11 manned module payload flights with 11 test and deployment flights using planned backup EVA.

7. However, carry-on experiments increase the likelihood of conflict, expecially in the future, specifically:

   - 1981 - No conflict because there are no pressure-sensitive carry-ons.

   - 1982 - No conflict identified to date because no pressure-sensitive carry-ons have been identified so far. There is one non-EVA flight available to accommodate any pressure-sensitive carry-ons.

   - 1983 to 1985 - Conflict potential increases as carry-ons become more numerous. Approximately 800 carry-ons are currently being considered, and many will be ready for flight in these years.

   - 1986 and beyond - Conflict potential continues to increase because current flight assignment planning becomes less firm, and more EVA flights are expected.

8. The following approaches have been identified for avoiding conflict between EVA and pressure sensitive payload requirements:

   a. Continue to assign manned module payloads and deployment-service-construction payloads to different flights.

   b. Avoid assigning pressure sensitive carry-on experiments to flights with planned or backup EVA.

   c. Operate Orbiter as a two-pressure vehicle: 14.7 psia for flights without EVA and reduced cabin pressure for flights with planned or backup EVA.

   d. Raise EVA pressure in several steps: 5.56 psia minimum for 1983, and 7.25 psia for 1986 and beyond.

Advantages of Approaches to Avoid EVA vs. Payload Conflicts:

- Module and carry-on experiment payload design is not affected, thus retaining existing benefits of STS for the payload user community.

Advantages of Approaches (Continued):

- Separating EVA and pressure sensitive carry-ons appears workable for the next few years, while carry-on traffic is light.
- Raising EVA pressure to at least 5.56 psia in the near future eliminates payload materials problems, permitting assignment of carry-ons to EVA flights if carry-ons will function at 11.6 psia. This will help relieve carry-on assignment problems as carry-on traffic increases.
- Raising EVA pressure to 7.25 psia further in the future eliminates the entire payload pressure sensitivity issue at that time.

STS Impacts:

- Orbiter will require an automatic two-schedule cabin pressure control system for the next few years. The low pressure schedule will require revision as EVA pressure is raised.
- Extensive operation of Orbiter at reduced cabin pressure will require evaluation of the following:
  - Cabin materials for use up to 33.4% $O_2$
  - Cycle life requirements for cabin negative relief provision
  - Power own of select air-cooled avionics and carry-on experiments
  - Procedures for eliminating $N_2$-rich gas pockets in the cabin during repressurization.
- Scheduling pressure sensitive carry-ons to non-EVA flights may be difficult if carry-on traffic becomes heavy.
- EMU will require significant modification to raise EVA pressure.

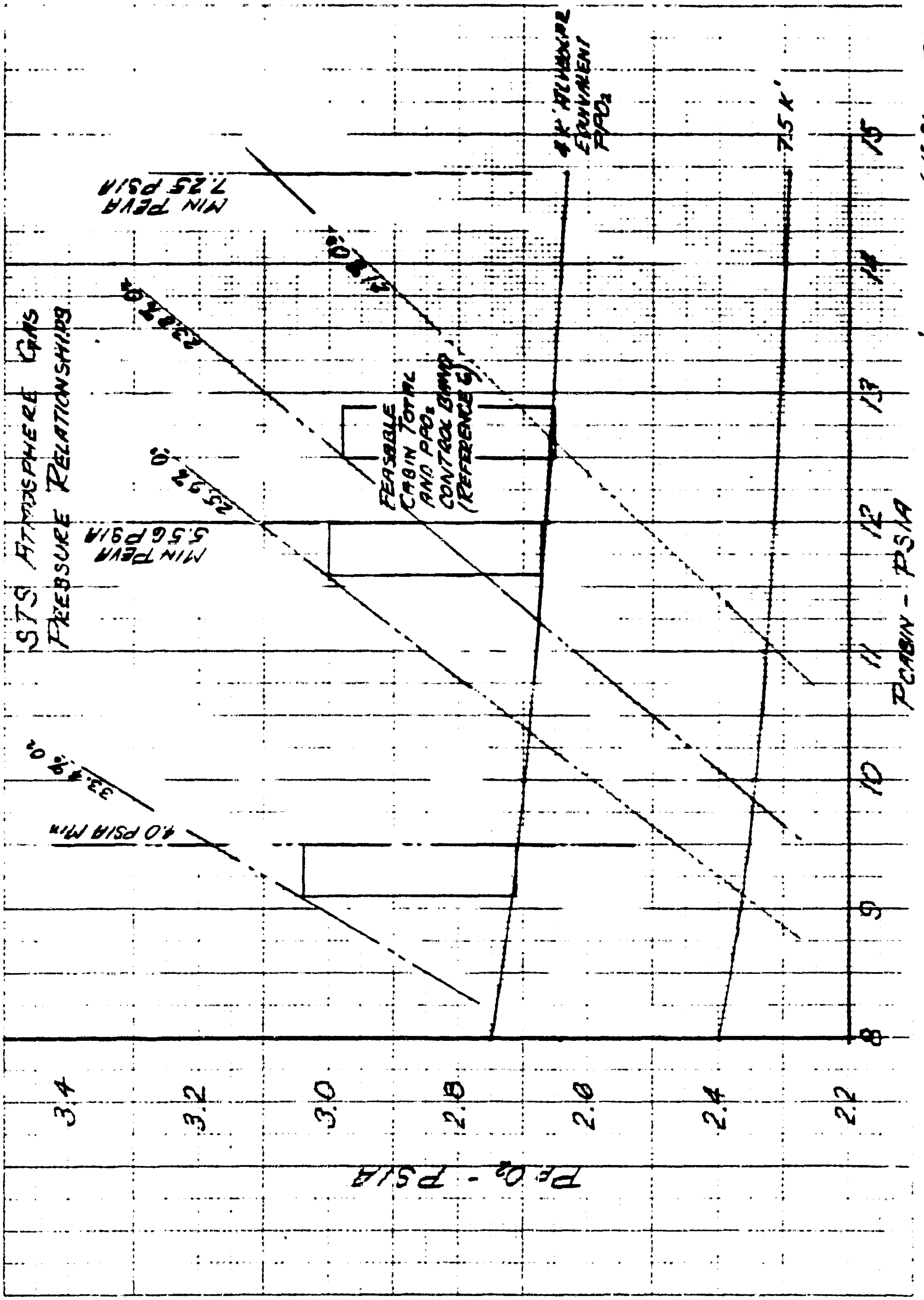
STS ATMOSPHERE GAS PRESSURE RELATIONSHIPS
MIN PEVA 7.25 PSIA
MIN PEVA 5.56 PSIA
4.0 PSIA Min
33.4% O2
25.9% O2
23.8% O2
FEASIBLE CABIN TOTAL AND PPO2 CONTROL BAND (REFERENCE 6)
4K' ALTITUDE EQUIVALENT PPO2
7.5 K'
3.4
3.2
3.0
2.8
2.6
2.4
2.2
8
9
10
11
12
13
14
15
PCABIN - PSIA
PPO2 - PSIA
6-12-81

Figure 1

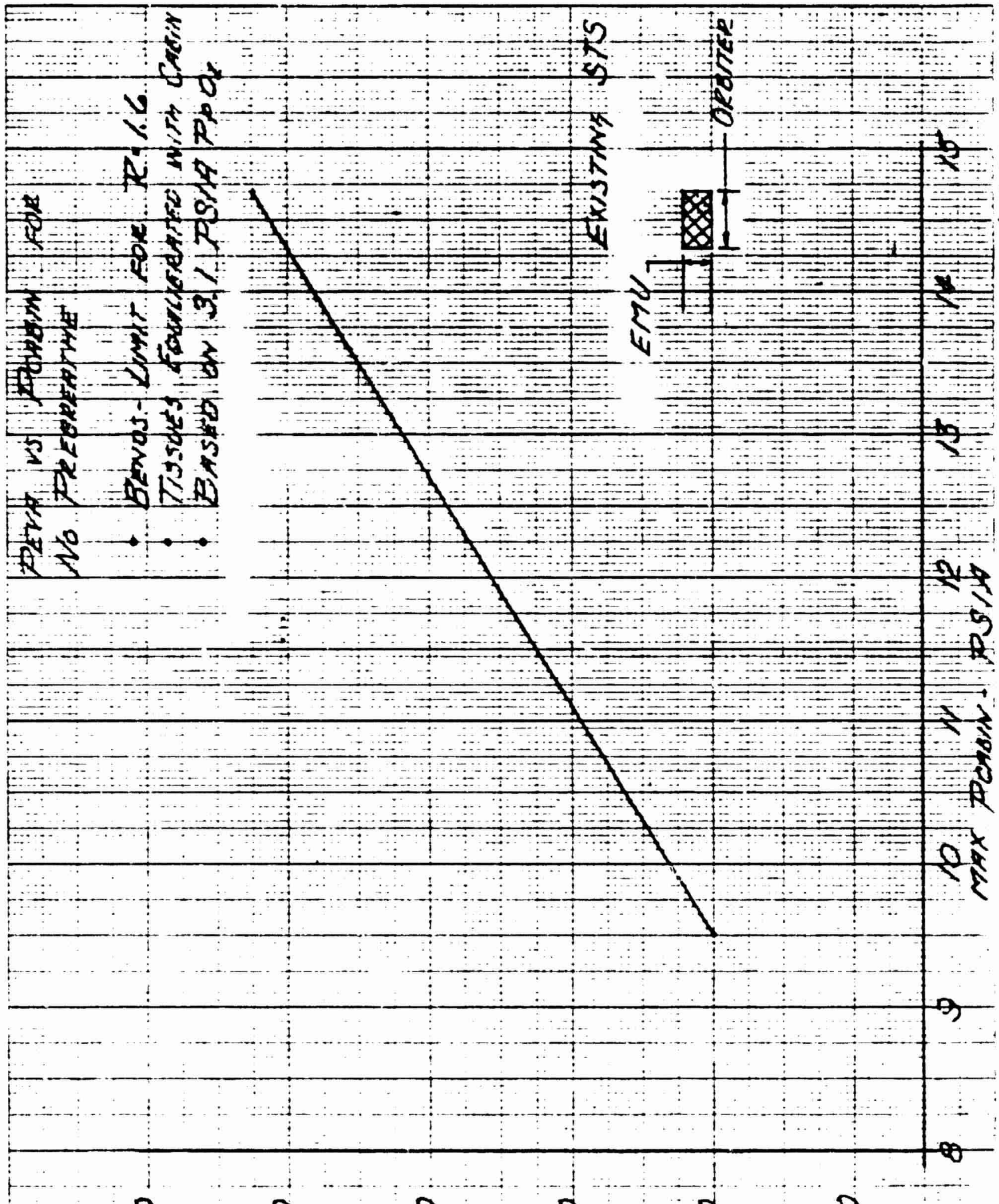


FIGURE 2

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## BACKGROUND

EVA planning for supporting STS flights calls for conducting EVA at 4.0 psia from a 14.7 psia cabin. To preclude "the bends", a painful and potentially dangerous physiological condition resulting from bubble formation when dissolved gasses in body tissues are driven out of solution by exposure to reduced ambient pressure during EVA, STS crewmembers prebreathe pure $O_2$ for 3 to 4 hours to purge body tissues of dissolved $N_2$, the prime constituent of bends bubbles. However, prebreathing has several drawbacks: the crew considers the Portable Oxygen System (POS) to restrict IVA prior to donning the EMU; and denitrogenation can be significantly reduced inadvertently during EMU donning by taking just one or two breaths of air, significantly increasing likelihood of bends, unless specific (and cumbersome) procedures are followed rigorously.

Planning for STS-1 side-stepped prebreathing by requiring reduction of cabin pressure to 9 psia for approximately 12 hours prior to EVA, which promotes sufficient washout of dissolved gasses from tissues to minimize likelihood of bends. This is not a permanent solution, because it does not address many Orbiter, payload, operational, and EVA issues relevant to operational STS flights. The objective of the Prebreathe Elimination Study is to define physiologically safe EVA and cabin pressure levels while achieving an acceptable compromise between conflicting Orbiter, payload, operational, and EVA issues. This memo on payload issues addresses relationships between EVA pressure and payloads. Other issues are being addressed elsewhere in the Prebreathe Elimination Study.

## PROBLEM STATEMENT

Prebreathe Elimination Study examines impacts of changing Orbiter cabin pressure and EMU EVA pressure to eliminate pure $O_2$ prebreathe prior to EVA. Because some classes of payloads are sensitive to cabin pressure, a blanket reduction of cabin pressure to support EVA could adversely affect some payload experiment results and payload materials selection. This could in turn reduce both user acceptance of STS in general and user acceptance of EVA for payload support. Hence it is important to assess impacts of EVA pressure on payloads and to identify approaches for minimizing conflicts between EVA and payloads.

This memo discusses key EVA and payload issues, namely:

- Relationship between EVA pressure and cabin pressure
- Payload sensitivity to reduced cabin pressure
- Correlation of flights with EVA and pressure sensitive payloads
- Future uncertainty about EVA and pressure sensitive payloads
- Approaches for minimizing conflict between EVA and pressure sensitive payload requirements.

## PAYLOAD AND EVA ISSUES

1. Relationship Between EVA Pressure and Cabin Pressure (Reference 1)

The relationship between cabin pressure and EVA pressure to avoid the bends is based on the ratio of total dissolved gas pressure in body tissues to EVA total pressure. For aviators and astronauts (as opposed to underwater divers) all dissolved gas, not just $N_2$, contributes to bubble growth. Empirical studies of bends susceptibility represent total tissue dissolved gas pressure by inspired $N_2$ pressure, and hence express the ratio of total dissolved gas in the tissues to EVA total pressure as:

1. $R = \frac{P\ IN_2}{P\ EVA}$

$PIN_2$ is the inspired $N_2$ partial pressure, taken as total breathing gas pressure minus $O_2$ partial pressure (3.1 psia in a normal atmosphere)

PEVA is the EVA total pressure.

NASA JSC Medical Science Division has agreed that R = 1.6 represents a safe value to minimize the probability of incurring the bends without prebreathing. Figure 2 shows a plot of cabin pressure to EVA pressure using this value of R. Because the existing EMU operates at 4 psi, there is no need to use a lower EVA pressure in the future. This sets the minimum cabin pressure to be considered at 9.5 psia, which is 0.5 psi higher than that planned for STS-1 EVA support.

2. Payload Sensitivity to Low Cabin Pressures

Economical delivery of payloads to orbit is the reason for STS's existence. Hence factors which reduce payload economy or effectiveness must be examined closely. Some payloads exposed to cabin pressure are pressure sensitive. Information return from these could be impaired by reducing cabin pressure. All payloads exposed to cabin pressure must use materials rated acceptable for exposure to $O_2$ concentrations up to 25.9%. Payloads exposed to higher $O_2$ concentrations may have material incompatibility problems.

Payloads may be classified into three broad categories: satellites, structures, and experiments. Boundaries between these classes may become blurred in the future, but this classification appears adequate for discussion of payloads to be launched during the next few years.

- Satellites -

  Satellites will be delivered to low earth orbit by STS. Appendages, such as solar panels and antennas, will be deployed; then the satellite will be activated, checked out, and released. A rocket stage may be attached to the satellite for boosting it to a different orbit. Satellites are carried in the Orbiter payload bay, and are not sensitive to cabin pressure.

- Structures -

No structure payloads have been booked to date for delivery to orbit, but structure concepts are being developed. Structures are expected to be deployed, assembled or fabricated in orbit, and are expected to consist ultimately of several or many individual payloads. Structure payloads, i.e., structural and mechanical elements and bulk materials, are not expected to be sensitive to cabin pressure.

- Experiments -

Experiments to date are assigned to payloads which remain with the Orbiter while in orbit. Experiments will be carried externally and internally. External experiments will be pallet-mounted and carried in the payload bay or will be mounted to various external surfaces of the Orbiter. External experiments are not sensitive to cabin pressure. Internal experiments will be carried both in Spacelab modules and in the cabin, and hence will be exposed to cabin atmosphere. These are the classes of payloads of which individual members may be pressure sensitive.

The NASA JSC Life Sciences Directorate considers many life science experiments, as exemplified by cardio-pulmonary experiments, to be pressure sensitive. Even the variation from sea level (14.7 psia) to 5000 feet at Denver (12.5 psia) may be significant. Experiments involving hematology are sensitive to $O_2$ concentration. Control experiments in both areas are being run at sea level because Spacelab and Orbiter have been designed to provide a sea-level atmosphere (Reference 3), and compensation for altitude effects may require more than simple gas law corrections. In addition, NASA JSC Medical Science Division has placed minimum limits on cabin $O_2$ concentration at the 4000 foot alveolar equivalent (Reference 1). Refer to Figure 1. This requires $O_2$ concentration to increase from sea-level values as cabin pressure is reduced. Thus reducing cabin pressure could alter information obtained from an experiment and may reduce the value of control experiments run at sea level.

Attachment 1 to this memo shows that life science experiments are currently assigned to the following Spacelab (S/L) module flights (Reference 2):

| | | | | | | |
|---|---|---|---|---|---|---|
| S/L - | 1 | 3 | 4 | D1 | 10 | 15 |
| STS - | 10 | 20 | 22 | 25 | 48 | 68 |
| Date | 6-83 | 10-83 | 5-84 | 8-84 | 11-85 | 9-86 |

Also, it is considered likely that life science experiments may be carried aboard other Spacelab module flights, even though the primary missions for these flights are for purposes other than life sciences (Reference 4). Attachment 1 shows the following other Spacelab module flight assignments to date (Reference 2):

| | | | | | |
|---|---|---|---|---|---|
| S/L - | 6 | 8 | 11 | 13 | Free-Flyer |
| STS - | 30 | 38 | 10V | 54 | 6V |
| Date | 12-84 | 5-85 | 8-86 | 5-85 | 12-85 |

In addition, cooling provisions for Spacelab experiments are based on a sea-level atmosphere. Cooling difficulties may be anticipated at cabin pressures below 12.5 psia (5000 foot altitude equivalent). Also, the Spacelab module materials are rated for a maximum $O_2$ concentration of 23.8%. This concentration could be exceeded with cabin pressures below 12.5 psia as shown in Figure 1. NASA is not willing at this time to consider imposing higher $O_2$ concentration requirements on module or module experiment materials. For all of these reasons this study considers all Spacelab module payloads to be pressure sensitive (Reference 4).

If EVA is necessary on these flights, present planning calls for transferring the crew out of the module, isolating the module at 14.5 psia, and keeping the maximum number of experiments operating to reduce the loss of payload experiment time. However, this plan reduces information output if experiment tending time were lost or reduces validity if the crewmembers themselves are test subjects (Reference 4).

Carry-on experiments are small payloads packaged into mid-deck lockers or stored on a mid-deck panel. Only five carry-ons have been identified to date: plant lignification, blood drawing, OSTA-2 flight deck camera, electrophoresis, and latex dispersion. The first three of these are scheduled to fly with STS 2, 4, 8, and 14. The last two have not yet been assigned to a flight (Reference 4). None of these five carry-ons is pressure sensitive. However, approximately 800 carry-on experiments are being considered, many from high schools and universities. Many of these experiments are expected to have pressure sensitive function and/or cooling. In addition, all carry-ons must meet existing safety requirements, which include materials acceptable for use at up to 25.9% $O_2$ (Reference 4). Figure 1 shows that experiments would require materials acceptable for Exposure to 33.4% $O_2$ to meet safety requirements of a 9.5 psia cabin NASA is unwilling to consider imposing such a restriction at this time.

3. Correlation of EVA and Payloads

STS planning identifies three categories of EVA (Reference 4).

- Planned - EVA is the baseline mode for accomplishing mission objectives. Mission support equipment is designed for operation by EVA. EVA costs are chargeable to the payload user.
- Backup - EVA is the backup mode for accomplishing mission objectives. Mission support equipment is designed for EVA to back up select non-redundant features. EVA costs are chargeable to the payload user.
- Contingency - EVA is a contingency mode for supporting safe return of the Orbiter to Earth. Tile repair and payload bay door closure are examples. Contingency EVA is a service provided by Orbiter to payload users.

Planned EVA -

Current planning calls for demonstration EVA's on STS-2 and 4. No other planned EVA's have been identified for the 79 flights identi[illegible]. Pallet payloads planned to date require no planned EVA. There are no [illegible] packs or experiment canisters to be retrieved. Space Telescope is the one payload currently being designed for EVA service. Telescope service has not yet been assigned to a flight. The telescope launch has been assigned to STS-16 and scheduled for launch during 1-84.

Telescope service flights are not expected before 1985. The 25 KW Power System, currently being concepted, will probably use EVA as baseline. Its launch date is not expected before 1986, which is near the end of current flight assignment planning (Reference 2). Its launch flight has not been assigned or scheduled to date. Future structures and satellites are expected to make increasing use of baseline EVA. PAM-A, a payload adapter module in the planning stage, is expected to use EVA. PAM-A flight assignment and schedule have not been made to date.

Backup EVA -

IUS is the only payload element designed for backup EVA. Its erector in the payload bay is designed for EVA assistance if it fails. Attachment 1 shows present planning for using IUS to boost the following commercial and NASA payloads to higher orbit.

| Payload | TDRS-A | B | C | D | Galileo | Solar-Polar | VOIR |
|---|---|---|---|---|---|---|---|
| STS - | 5 | 7 | 12 | 15 | 18 & 19 | 35 & 36 | 59 |
| Date | 9-82 | 12-82 | 8-83 | 12-83 | 2,3-84 | 3,4-85 | 5-86 |

Contingency EVA -

EMU's are carried on each STS flight to cover the requirement for contingency EVA. In situations requiring contingency EVA, loss of experimentat data, experimental time, or experiment equipment becomes secondary to returning the Orbiter safely to Earth. STS flight plans contain provision for contingency EVA on all flights (Reference 5). Hence payload flight assignment is not affected by the possibility of performing contingency EVA on any particular flight.

Table 1 presents a year-by-year summary of planned STS flights and highlights potential conflicts between flights carrying pressure sensitive payloads and flights with planned or backup EVA. The following conclusions can be drawn from Table 1.

- At the present time there is no planned or backup EVA anticipated for flights with pressure sensitive payloads.

- Carry-on experiments represent uncertainty. Because pressure sensitivity and flight assignment for most carry-ons have yet to be determined, carry-ons represent the major source of potential conflict between EVA and pressure sensitive payloads out through current flight assignment planning, which is September, 1986.

4. Future Uncertainty About EVA and Pressure Sensitive Payloads

Uncertainty about payloads assignment increases in the future. This study is based on the NASA Flight Assignment Baseline (Reference 2). This document is a moving target, and is updated quarterly to reflect program impacts and other changes. Payload integration planning using this document extends out to Spacelab D-1, which is assigned to STS-25 and scheduled for launch in August, 1984. Beyond that, most payloads are firm, i.e., individual payloads identified and grouped into a single payload for delivery by a single flight to a particular orbit, out to STS-44, scheduled for launch September, 1985. Other payloads scheduled for launch out to September 1986 may be less certain. Many of these are reflights, payloads of opportunity or others that have not yet been officially booked. Booked means a payload has been defined and its launch need date established, and it has been budgeted or its earnest launch money has been deposited (Reference 2). Looking beyond 1986 reveals still more uncertainty. As already mentioned, Space Telescope service has not been assigned to a flight. Other payloads such as 25 KW Power System and PAM-D are still in the planning stage, and Space Operations Center is still being concepted. The correlation between flight assignments for EVA payloads and pressure sensitive payloads is undefined in this time period.

5. Approaches for Minimizing Conflict Between EVA and Pressure Sensitive Payloads

- Continue present practice of not assigning module payloads to flights planned for EVA support - Attachment 1 shows that current planning dedicates separate flights for module payloads, thus separating them from deployment payloads which may use EVA. This approach retains present module materials and experiments, and hence has no impact on the payload user community.

- Assign pressure sensitive carry-ons to non-EVA flights - Table 1 shows that no conflict exists at present for 1981 flights because there are no pressure sensitive payloads scheduled for launch in 1981.

  In 1982 three out of four flights may use EVA. With no pressure sensitive payloads identified to date for 1982, it appears likely that several such carry-ons, if identified, could be assigned to the one non-EVA flight.

  By 1983 carry-on traffic is expected to increase. While only two out of eight flights may use EVA, some difficulty may be found in assigning pressure sensitive carry-ons to the remaining six flights. The most desirable situation would be to assign any pressure sensitive carry-ons to the Spacelab 1 flight, which already carries a pressure sensitive module. Similar situations exist in 1984 and 1985, where it would be desirable to assign pressure sensitive carry-ons first to module flights and second to deployment flights for which no baseline or backup EVA is planned. This approach appears workable for the next few years while carry-on traffic is light. Scheduling difficulties might be encountered as carry-on traffic gets heavier. This approach retains present carry-on materials usage and equipment design, and hence has no adverse impact on the carry-on user community.

- Operate Orbiter as a two-pressure vehicle - Equip Orbiter with a two-schedule automatic cabin pressure control system which allows 14.7 psia operation when carrying pressure sensitive payloads but permits reduction of cabin pressure to support EVA during satellite service and deployment and structure construction flights. This approach requires retaining procedures similar to those available for STS-1 for cabin pressure reduction, power-down of air-cooled avionics, and elimination of $N_2$-rich pockets in the cabin during repressurization. Continuing cabin depressurization into the operational flight phases also requires examining Orbiter cabin materials, cycle life requirements on the cabin negative pressure relief provisions, and effects on water and waste management subsystems.

- <u>Raise EVA Pressure</u> - Raising EVA pressure will permit assigning carry-ons to non-Spacelab module flights with planned or backup EVA. Figure 2 shows that raising EVA pressure to 5.56 psi will permit raising cabin pressure during pre-EVA activities to 11.6 psia. Figure 1 shows that 11.6 psia permits physiologically safe $O_2$ levels without exceeding material standards to which carry-ons are being designed. This removes the materials constraint and allows assigning carry-ons that can operate at 11.6 psia to flights with planned or backup EVA. EMU modifications are reuqired to raise EVA pressure to 5.56 psia, but availability in 1983 appears feasible.

  EVA flights are expected to increase significantly in 1986 and beyond to support projected satellite service and construction activity. This may reduce scheduling opportunities for carry-ons which do not function at subatmospheric pressures. Figure 2 shows that raising EVA pressure to 7.25 psia will permit use of 14.7 psia cabin pressure even during EVA support. This would lift all constraints and resolve all conflicts in assigning pressure sensitive payloads to flights with planned or backup EVA.

  These approaches are not mutually exclusive. A workable compromise between conflicting requirements of EVA and pressure sensitive payloads is expected to employ all approaches in the time period from the present until EVA pressure is raised to 7.25 psia.

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  These approaches are not mutually exclusive. A workable compromise between conflicting requirements of EVA and pressure sensitive payloads is expected to employ all approaches in the time period from the present until EVA pressure is raised to 7.25 psia.

REFERENCES


1. Memo ECWS-PBE-01, Rev. A, "Prebreathe Elimination Study - Physiological Aspects," Richard C. Wilde, Hamilton Standard, April 1981.

2. JSC 13000-5, "STS Flight Assignment Baseline," STS Operations - NASA Headquarters, December 15, 1980.

3. Telecon with S. Luczkowski of NASA JSC, SE4, March 10, 1981.

4. Meeting with J. O'Loughlin and R. Zedekar of NASA JSC PF, March 25, 1981.

5. JSC-16751, "STS-1 Flight Data File EVA Operations Book," NASA JSC, January 2, 1981.

6. Memo ECWS-PBE-03, Preliminary, "Prebreathe Elimination Study - Cabin Pressure and Materials Issues," Richard C. Wilde, Hamilton Standard, May 1981.

TABLE 1

**Potential Conflicts Between Pressure Sensitive Payloads and EVA**

| Year | Flights Planned | Flights w/EVA | | Flights w/Pressure Sensitive Payloads | | Potential Conflicts |
|---|---|---|---|---|---|---|
| | | Planned | Backup | Module | Carry-on | |
| 1981 | 3 | 1 (STS-2) | 0 | 0 | 0 | None |
| 1982 | 4 | 1 (STS-4) | 2 (STS-5,7) | 0 | TBD | None at present. Avoid PSCs w/payloads assigned to STS-5&7. |
| 1983 | 8 | 0 | 2 (STS-12,15) | 1 (STS-10) | TBD | None at present. Avoid PSCs w/payloads assigned to STS-12&15. |
| 1984 | 17 | 0 | 2 (STS-18,19) | 4 (STS-20,22, 25,30) | TBD | None at present. Avoid PSCs w/payloads assigned to STS-18&19. |
| 1985 | 24 | 0 | 2 (STS-35,36) | 3 (STS-38,48, 6V) | TBD | None at present. Avoid PSCs w/payloads assigned to STS-35&36. |
| 1986 | 23 | 0 | 1 (STS-59) | 3 (STS-54, 10V,6B) | TBD | None at present. Avoid PSCs w/payloads assigned to STS-59. |
| Total | 79 | 2 | 9 | 11 | TBD | |
| Foreseeable Future (Middle '80's to early '90's) | | TBD (ST Service, 25 KW PS) | TBD (PAM-A) | TBD (S/L Modules) | TBD | Avoid PSCs on flights to support ST service and 25 KW PS deployment/construction. |
| | | (Satellite Service, SOC) | | - | TBD | Avoid PSCs on flights to support Satellite service and SOC deployment/construction. |

PSCs = Pressure Sensitive Carry-on Experiments
= Space Telescope
25 KW PS = Power System
SOC = Space Operations Center

R. Wade 4/22/81

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ATTACHMENT

# STS FLIGHT ASSIGNMENT BASELINE - SUMMARY

| MISSION | | | | | | PAYLOAD | | | | | | | CREW | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STS FLT | DATE | USER | STATUS | PURPOSE | CARRY-ON | SPACELAB | MODULE | PALLET | BOOSTER | CARRIER | RMS | PRES-SENSITIVE | EVA | CREW/DURATION | DATA SOURCE |
| 1 | 4-12-81 | NASA | Complete | OFT- DFI, IECM | No | No | No | No | No | n/a | No | No | Contin. | 2 / 3 | 1, 2, 7 |
| 2 | 9-30-81 | NASA | Firm | OFT- DFI, IECM, OSTA 1 | Plant Watering Mtrl for S/C 2, Blood Drawing | No | No | OFT | No | n/a | YES | No | Planned DTO-Dmg. | 2 / 5 | 1, 3, 4, 7, 8, 9 |
| 3 | 12-31-81 | NASA | Firm | OFT- DFI, IECM, PFTA | - | No | No | No | No | Special Struct | YES | No | Contin | 2 / 7 | 1, 4, 7 |
| 4 | 4-30-82 | NASA | Firm | OFT- DFI, IECM, OSS-1 AAS Test Art | Plant Lignification | No | No | OFT | No | n/a | No | No | Unplanned DTO Demo | 2 / 7 | 1, 2, 3, 4, 7, 8, 9 |
| 5 | 9-15-82 | Commercial | Firm | TDRS-A | - | No | No | No | IUS-2 | n/a | No | No | Back-up | 2 / 2 | 1, 7 |
| 6 | 11-18-82 | Foreign, Commercial | Firm | SPAS-01, SBS-C, Telesat B, Intelsat A(F5) | - | No | No | No | SSUS D, SSUS A | Unique Struct | YES | No | Contin | 3 / 5 | 1, 7 |
| 7 | 12-16-82 | NASA Commercial | Firm | OAST-1 (SEPS) TDRS-B | - | No | No | No | IUS-2 | Special Struct. | YES | No | Back-up | 3 / 2 | 1, 3, 4, 7 |
| 8 | 2-11-83 | NASA, Foreign, Commercial | Firm | OSTA-2, Telesat F, RCA-C, Intelsat A(F6) | AFS Camera | No | No | No | SSUS-D, SSUS-A | Special Struct. | No | No | Contin. | 3 / 5 | 1, 2, 4, 7 |
| 9 | 4-22-83 | DOD | Booked | DOD 83-1 | - | No | - | - | - | - | - | - | - | - | 1 |
| 10 | 6-5-83 | NASA, Foreign | Firm | Earth Obs, Atmospheric, Life Sci, Matls Technol. | Gaseous + Life Sci Catalyst | 1 | Long | 1 | No | No | Yes | Yes | Contin. | 6 / 7 | 1, 2, 4, 7 |
| 11 | 7-8-83 | DOD | Booked | DOD 83-2 | - | No | - | - | - | - | - | - | - | - | 1 |
| 12 | 8-26-83 | Foreign, Commercial | Firm | INSAT-1A, TDRS-C | - | No | No | No | SSUS-D, IUS-2 | No | No | No | Back-up | 3 / 3 | 1, 7 |
| 13 | 10-4-83 | DOD | Booked | DOD 83-3 | - | No | - | - | - | - | - | - | - | - | 1 |
| 14 | 10-31-83 | NASA | Firm | Earth Obs, Cosmic Ray | Plant Lignification, Blood Drawing | 2 | No | 1+2 | No | Unique Struct | Yes | No | Contin. | 6 / 7 | 1, 2, 4, 6, 7 |
| 15 | 12-16-83 | Foreign Commercial | Firm | Insat-1B, TDRS-D | - | No | No | No | SSUS-D, IUS-2 | No | No | No | Back-up | 3 / 3 | 1, 7 |
| 16 | 1-12-84 | NASA | Firm | OMS Kit, Space Telescope | - | No | No | No | No | Unique Struct | Yes | No | Contin. | 3 / 3 | 1, 7 |
| 17 | 1-31-84 | NASA, Foreign, Commercial | Firm | MPS-1, Palapa-B1, RCA-F, Syncom-IV-1 | - | No | No | OFT | SSUS-D, Unique | No | Yes | No | Contin | 3 / 7 | 1, 7 |
| 18 | 2-20-84 | NASA | Firm | Galileo Orbiter | - | No | No | No | IUS-3 | No | No | No | Back-up | 2 / 1 | 1, 7 |
| 19 | 3-15-84 | NASA | Firm | Galileo Probe | - | No | No | No | IUS-3 | No | No | No | Back-up | 2 / 1 | 1, 7 |
| 20 | 4-10-84 | NASA | Firm | Animals, Other | + | 3 | Long | 1 | No | No | Yes | Yes | Contin. | 6 / 7 | 1, 2, 7 |
| 21 | 4-26-84 | Foreign, Commercial | Firm | Palapa-B2, Telesat I, Arabsat-A, Syncom IV-2 | + | No | No | No | SSUS-D, Unique | No | Yes | No | Contin | 3 / 5 | 1, 7 |
| 22 | 5-22-84 | NASA | Firm | Life Sciences, EOS | + | 4 | Long | No | No | Unique Struct | Yes | Yes | Contin | 6 / 7 | 1 2 7 |
| 23 | 6-15-84 | TBD | TBD | Reflight Opportunity | + | TBD | TBD | TBD | TBD | TBD | TBD | TBD | TBD | TBD | 1 |
| IVA | 6-27-84 | NASA | Planned | NOAA-H | - | No | No | No | Unique | No | - | No | Contin. | 2 / 2 | 1, 7 |
| 24 | 7-10-84 | NASA, Foreign, Commercial | Firm | OSS-2, Arabsat-B, AT&T-2, SBS-D | + | No | No | OFT | SSUS-D | No | Yes | No | Contin | 4 / 7 | 1, 7 |
| 25 | 8-15-84 | Foreign | Firm | SMET (Incl Vestibular Sled) | + | D1 | Long | Special | No | No | Yes | Yes | Contin. | 6 / 7 | 1, 7 |
| 26 | 9-7-84 | NASA Commercial | Firm | OSTA-3, RCA-G, GSTAR-A, Syncom IV-3 | - | No | No | | SSUS-D, Unique | Special Struct | Yes | No | Contin | 3 / 5 | 1, 7 |

1- JSC 13,000-5 Flight Assignment Baseline 12-15-80
2- Memo L S Lucas [illegible] R E Michel JSC 11-3-80
3- Telecon w/ L Lucas [illegible] 3-2-81
4- Telecon w/ Hugh Scott 3-10-81
5- Telecon w/ Al Jones 3-17-81
6- Telecon w/ [illegible] 3-10-81
7- Memo [illegible]
8- [illegible]
9- Telecon w/ [illegible] 6-8-81



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Sheet 2 of 2

# STS Flight Assignment Baseline - Summary

| Mission | | | | | | Payload | | | | | | | Crew | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STS Flt. | Date | User | Status | Purpose | Carry-On | Space-Lab | Module | Pallet | Booster | Carrier | RMS | Pers. Sensitive | EVA | Crew/ Duration | Data Source |
| 27 | 10-4-84 | NASA | Firm | LDEF Deploy (UP) SMM Return (DN) OMS Kit | - | No | No | No | No | LDEF FSS | Yes | No | Contin | 3 / 3 | 1, 7 |
| 28 | 10-19-84 | NASA, Foreign, Commercial | Firm | MPS-1, Domsat-A Intelsat-C | - | No | No | OFT | SSUS-D SSUS-A | - | Yes | No | Contin | 3 / 7 | 1, 4, 7 |
| 1V | 10- -84 | DOD | Planned | DOD BS-1V | - | No | - | - | - | - | - | - | - | - | 1 |
| 29 | 11-13-84 | DOD | Booked | DOD BS-1 | - | No | - | - | - | - | - | - | - | - | 1 |
| 30 | 12-5-84 | NASA | Firm | Solar-Terrestrial | - | 6 | Short | 3 | No | No | Yes | Yes | Contin | 6 / 7 | 1 |
| 31 | 1-3-85 | DOD | Booked | DOD BS-2 | - | No | - | - | - | - | - | - | - | - | 1 |
| 32 | 1-22-85 | NASA, Commercial | Firm | OSS-3 AT&T-3, RCA-H, Syncom IV-4 | - | No | No | OFT | SSUS-D Unique | No | Yes | No | Contin | 4 / 7 | 1, 7 |
| 2V | 2- -85 | DOD | Planned | DOD BS-2V | - | No | - | - | - | - | - | - | - | - | 1 |
| 33 | 2-12-85 | DOD | Booked | DOD BS-3 | - | No | - | - | - | - | - | - | - | - | 1 |
| 34 | 2-28-85 | NASA | Firm | Astrophysics | - | 5 | No | 2+2 | No | No | Yes | No | Contin | 6 / 7 | 1 |
| 35 | 3-26-85 | NASA | Firm | Solar Polar (ESA) | - | No | No | No | IUS-3 | No | No | No | Back-up | 2 / 1 | 1, 7 |
| 3V | 4- -85 | DOD | Planned | DOD BS-3V | - | No | - | - | - | - | - | - | - | - | 1 |
| 36 | 4-25-85 | NASA | Firm | Solar Polar (NASA) | - | No | No | No | IUS-3 | No | No | No | Back-up | 2 / 1 | 1, 7 |
| 37 | 5-11-85 | DOD | Booked | DOD BS-4 | - | No | - | - | - | - | - | - | - | - | 1 |
| 38 | 5-30-85 | NASA | Firm | Mat'l Processing | - | 8 | Long | 1 | No | No | Yes | Yes | Contin | 6 / 7 | 1, 7 |
| 39 | 6-25-85 | NASA Commercial | Firm | X-Ray Observatory Syncom IV-5 | - | No | No | No | Unique | No | Yes | No | Contin | 3 / 3 | 1, 7 |
| 40 | 7-12-85 | NASA, Foreign, Commercial | Firm | OSTA-4, Domsat-B, Intelsat-D, GSTAR-A | - | No | No | No | SSUS-D SSUS-AD | Special Structure | Yes | No | Contin | 3 / 5 | 1, 7 |
| 4V | 7- -85 | TBD | Planned | Reflight Opportunity | - | TBD | TBD | TBD | TBD | TBD | TBD | TBD | TBD | TBD | 1 |
| 41 | 7-31-85 | Foreign | Firm | EMET | - | D4 | No | 2+2 | No | No | Yes | No | Contin | 6 / 7 | 1 |
| 42 | 8-20-85 | DOD | Booked | DOD BS-5 | - | No | - | - | - | - | - | - | - | - | 1 |
| 43 | 9-10-85 | TBD | TBD | Reflight Opportunity | - | TBD | TBD | TBD | TBD | TBD | TBD | TBD | TBD | TBD | 1 |
| 44 | 9-30-85 | NASA, Foreign, Commercial | Firm | OSS-4, IRIS, Intelsat-E | - | No | No | OFT | Unique SSUS-A | No | Yes | No | Contin | 4 / 7 | 1, 7 |
| 45 | 10-16-85 | NASA | Booked | Earth Observation | - | 7 | No | 2+2 | No | No | TBD | No | Contin | 6 / 7 | 1, 7 |
| 5V | 10- -85 | DOD | - | DOD BS-1V | - | No | - | - | - | - | - | - | - | - | 1 |
| 46 | 11-05-85 | NASA, Foreign | Booked | MPS-3 EUVE Telesat-[illegible], Domsat-[illegible] | - | No | No | OFT | SSUS-D | No | TBD | No | Contin | 3 / 2 | 1, 7 |
| 47 | 11-19-85 | DOD | - | DOD BA-1 | - | No | - | - | - | - | - | - | - | - | 1, 7 |
| 48 | 11-27-85 | NASA | - | Life Sciences | - | 10 | Long | 1 | No | No | TBD | Yes | Contin | 6 / 7 | 1, 7 |

R. Wade Ansley
Sheet 2 of 2

## STS FLIGHT ASSIGNMENT BASELINE - SUMMARY

| MISSION | | | | | | PAYLOAD | | | | | | | CREW | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STS FLT | DATE | USER | STATUS | PURPOSE | CARRY-ON | SPACE-LAB | MODULE | PALLET | BOOSTER | CARRIER | RMS | PROX-SENSITIVE | EVA | CREW/DURATION | DATA SOURCE |
| 49 | 12-17-85 | FOREIGN COMMERCIAL | BOOKED | DBS LUX-1 GOES-G, INTELSAT VI-1 | - | No | No | No | SSUS-D SSUS-DA | No | TBD | No | CONTIN. | 3 2 | 1,7 |
| 6V | 12- -85 | NASA | - | FREE FLYER | - | No | TBD | TBD | TBD | TBD | TBD | TBD | TBD | TBD | 1 |
| 50 | 1-7-86 | - | - | SOLAR PHYSICS | - | 16 | No | 2+2 | No | No | TBD | No | CONTIN. | 6 7 | 1,7 |
| 51 | 1-17-86 | DOD NASA + TBD | - | DOD 86-2 OSS-5 | - | No | - | - | - | - | - | - | - | - | 1 |
| 52 | 2-7-86 | | - | PAYLOAD OF OPPORTUNITY | - | No | TBD | OFT | TBD | TBD | TBD | TBD | TBD | 4 2 | 1 |
| 7V | 2- -86 | TBD | - | REFLIGHT OPPORTUNITY | - | TBD | TBD | TBD | TBD | TBD | TBD | TBD | TBD | TBD | 1 |
| 53 | 2-25-86 | DOD | BOOKED | DOD 85-6 | - | No | - | - | - | - | - | - | - | - | 1 |
| 54 | 3-5-86 | - | | MATERIALS SCIENCE | - | 13 | LONG | 1 | No | No | - | YES | CONTIN. | 6 7 | 1,7 |
| 55 | 3-25-86 | NASA | BOOKED | LDEF-1 RETRIEVE OMS KIT | - | No | No | No | No | LDEF | - | No | CONTIN. | 5 3 | 1,7 |
| 56 | 4-8-86 | TBD | - | REFLIGHT OPPORTUNITY | - | TBD | TBD | TBD | TBD | TBD | TBD | TBD | TBD | TBD | 1 |
| 8V | 4- -86 | DOD | - | DOD-2V | - | No | - | - | - | - | - | - | - | - | 1 |
| 57 | 4-11-86 | TBD NASA | - | REFLIGHT OPPORTUNITY OSS-6 | - | TBD | TBD | TBD OFT | TBD | TBD | TBD | TBD | TBD | TBD | 1 |
| 58 | 5-6-86 | TBD | - | PAYLOAD OF OPPORTUNITY | - | No | TBD | | TBD | TBD | TBD | TBD | TBD | 4 2 | 1 |
| 59 | 5-20-86 | NASA | - | VOIR | - | No | No | No | IUS-3 | No | TBD | No | BACK-UP | 5 1 | 1,7 |
| 60 | 5-29-86 | - | - | ASTROPHYSICS | - | 9 | No | 2+2 | No | No | TBD | No | CONTIN. | 6 7 | 1,7 |
| 61 | 6-17-86 | DOD | - | DOD 86-4 | - | No | - | - | - | - | - | - | - | - | 1 |
| 9V | 6- -86 | NASA TBD | BOOKED - | COBE, TBD | - | No | TBD | TBD | TBD | TBD TBD | TBD | No TBD | TBD | 3 | 1 |
| 62 | 7-2-86 | NASA | - | LDEF-2 DEPLOY, OMS KIT OSTA-5 | - | No | No | No | No | LDEF, SPECIAL | TBD | No | CONTIN. | 3 5 | 1,7 |
| 63 | 7-9-86 | TBD | - | REFLIGHT OPPORTUNITY | - | TBD | TBD | TBD | TBD | TBD | TBD | TBD | TBD | TBD | 1 |
| 64 | 8-05-86 | DOD | - | DOD 86-5 | - | No | - | - | - | - | - | - | - | - | 1 |
| 65 | 8-12-86 | NASA, TBD | BOOKED | MPS-4 PAYLOAD OF OPPORTUNITY | - | No | TBD | TBD | TBD | OFT TBD | TBD | TBD | TBD | 3 7 | 1 |
| 10V | 8- -86 | - | | SPACE PLASMA | - | 11 | SHORT | 3 | No | No | TBD | YES | CONTIN. | 6 7 | 1,7 |
| 66 | 9-3-86 | TBD | - | REFLIGHT OPPORTUNITY | - | TBD | TBD | TBD | TBD | TBD | TBD | TBD | TBD | TBD | 1 |
| 67 | 9-16-86 | TBD | - | REFLIGHT OPPORTUNITY | - | TBD | TBD | TBD | TBD | TBD | TBD | TBD | TBD | TBD | 1 |
| 68 | 9-24-86 | - | - | LIFE SCIENCES | - | 15 | LONG | 1 | No | No | No | YES | CONTIN. | 6 7 | 1,7 |



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ECWS-PBE-03

# PREBREATHE ELIMINATION STUDY - CABIN PRESSURE AND MATERIALS ISSUES

Richard C. Wilde
Engineering Manager, Advanced EVA Studies

July 1981

Hamilton Standard Division
United Technologies Corporation

MEMO HIGHLIGHTS

Title: Prebreathe Elimination Study - Cabin Pressure and Materials Issues

Object of Memo:

Identify cabin pressures that are consistent with physiological and materials $O_2$ partial pressure limits and that are achievable using Orbiter cabin pressure control equipment. Identify scope of materials investigation effort required to support high cabin $O_2$ concentration required at low cabin total pressure.

Nature and Scope of Study:

This investigation is based upon minimizing the cabin $PPO_2$ control band using present or available Orbiter equipment. The investigation also uses material evaluations performed to date as the basis for defining the scope of additional materials $O_2$ compatibility studies.

Findings and Conclusions:

1. It appears feasible to control and annunciate cabin $PPO_2$ within a total band of 0.33 psi using the existing cabin $O_2/N_2$ controller, the new 1.5% $PPO_2$ sensor and new C&W limit proms. These limits are shown in Figure 1.

2. The 0.33 psi $PPO_2$ control band permits reduction of cabin pressure down to 10.3 psia nominal while retaining $PPO_2$ between the minimum physiological limits and maximum materials compatibility limits deemed acceptable for STS-1 EVA support (30%). Cabin pressure can be reduced to 11.8 psia nominal without exceeding 25.9% $O_2$ deemed acceptable for normal STS-1 operation or 12.5 psia nominal without exceeding 23.8% $O_2$, the present Spacelab upper $PPO_2$ limit.

3. For cabin pressures below 10.3 psia nominal, a materials evaluation is required that is comparable to the investigation performed by NASA JSC ES5 to assess 216 major use materials in the Orbiter cabin for use at 30% $O_2$. Total cost of that effort was approximately $150 K.

4. Addition of a third mechanical regulator permits operation of the Orbiter at reduced cabin pressure for EVA flights while retaining 14.7 psia cabin pressure for Spacelab Module flights.

Advantages of Findings and Conclusions:

- Use of present equipment supports significant reduction in the $PPO_2$ control band. The significant contributor to the reduction is the $\pm$ 1.5% $PPO_2$ sensor, which was recently installed in OV102.

- The resulting $PPO_2$ control band supports a significant reduction in cabin pressure, which in turn will support EVA without prebreathe in the vicinity of 6 psia without impacting cabin or Spacelab materials.

Disadvantages of Findings and Conclusions:

- Resetting C&W limits to within the 0.33 psi band requires replacing C&W proms and reselling $O_2/N_2$ controller. The cost is $120 K.

- $O_2$ compatibility of cabin materials requires consideration at cabin pressures below 10.3 psia nominal. Assessment will cost approximately $150 K.

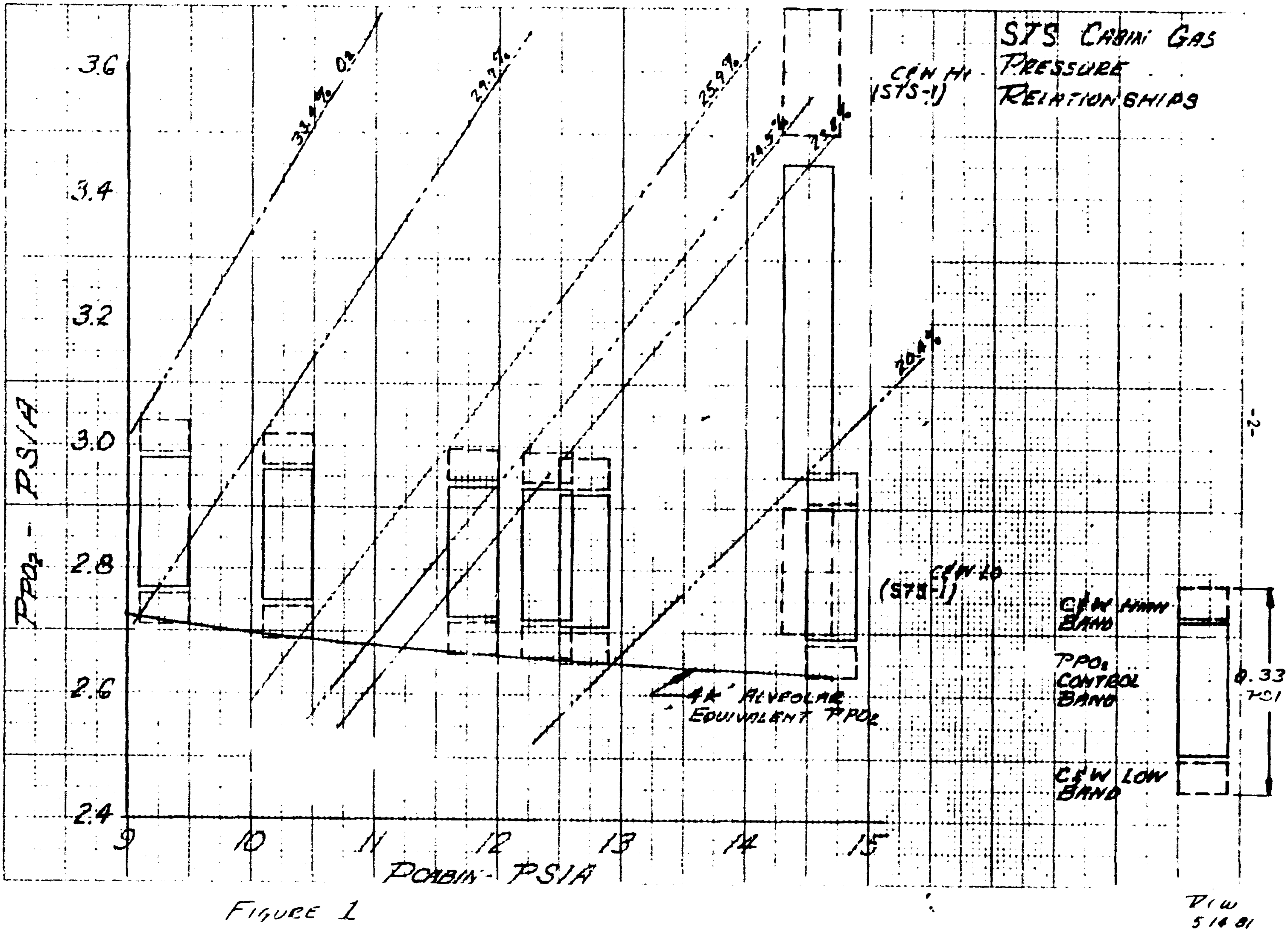
STS CABIN GAS
PRESSURE
RELATIONSHIPS
C&W HI
(STS-1)
C&W LO
(STS-1)
C&W HIGH BAND
PPO2 CONTROL BAND
C&W LOW BAND
0.33 PSI
33.4% O2
29.9%
25.9%
24.5%
23.8%
20.9%
4K' ALVEOLAR EQUIVALENT PPO2
3.6
3.4
3.2
3.0
2.8
2.6
2.4
PPO2 - PSIA
9
10
11
12
13
14
15
PCABIN - PSIA
DIW
5 14 81

FIGURE 1

Disadvantages of Findings and Conclusions: (Continued)

- Space is limited in the vicinity of middeck panel M010W for installation of additional cabin pressure regulators. Estimated cost is approximately $250 K.

BACKGROUND

EVA planning for supporting STS flights calls for conducting EVA at 4.0 psia from a 14.7 psia cabin. To preclude "the bends", a painful and potentially dangerous physiological condition resulting from bubble formation when dissolved gasses in body tissues are driven out of solution by exposure to reduced ambient pressure during EVA, STS crewmembers prebreathe pure $O_2$ for 3 to 4 hours to purge body tissues of dissolved $N_2$, the prime constituent of bends bubbles. However, prebreathing has several drawbacks: the crew considers the Portable Oxygen System (POS) to restrict IVA prior to donning the EMU, and denitrogenation can be significantly reduced inadvertently during EMU donning by taking just one or two breaths of air, significantly increasing likelihood of bends, unless specific (and cumbersome) procedures are followed rigorously.

Planning for STS-1 side-steps prebreathing by requiring reduction of cabin pressure to 9 psia for approximately 12 hours prior to EVA, which promotes sufficient washout of dissolved gasses from tissues to minimize likelihood of bends. This is not a permanent solution, because it does not address many Orbiter, payload, operational, and EVA issues relevant to operational STS flights. The objective of the Prebreathe Elimination Study is to define physiologically safe EVA and cabin pressure levels while achieving an acceptable compromise between conflicting Orbiter, payload, operational, and EVA issues. This memo addresses issues involving cabin pressure and cabin materials. Other issues are being addressed elsewhere in the Prebreathe Elimination Study.

PROBLEM STATEMENT

Prebreathe Elimination Study examines impacts of changing Orbiter cabin pressure and EMU EVA pressure to eliminate pure $O_2$ prebreathe prior to EVA. Because physiological requirements set minimum levels of cabin oxygen partial pressure, reduction of cabin total pressure raises cabin oxygen concentration. Cabin material flammability is sensitive to oxygen concentration. Maximum oxygen concentration limits for significant numbers of cabin materials can be exceeded within the range of reduced cabin pressures under consideration in this study. Hence it is important to assess the relationships between cabin pressure and cabin oxygen concentration and identify impacts of selecting low cabin pressures.

This memo discusses key cabin pressure and materials issues, namely:

- Relationship between EVA pressure and cabin pressure
- Cabin pressure control
- Relationship of cabin pressure to cabin oxygen concentration
- Impacts of high cabin oxygen concentration on cabin materials.
- Implementation of two-pressure control.

## CABIN PRESSURE AND MATERIALS ISSUES

1. Relationship Between EVA Pressure and Cabin Pressure (Reference 1)

The relationship between cabin pressure and EVA pressure to avoid the bends is based on the ratio of total dissolved gas pressure in body tissues to EVA total pressure. For aviators and astronauts all dissolved gas contributes to bubble growth. Empirical studies of bends susceptibility represent total tissue dissolved gas pressure by inspired $N_2$ pressure, and hence express the ratio of total dissolved gas in the tissues to EVA total pressure as:

1. $$R = \frac{P\ IN_2}{P\ EVA}$$

$PIN_2$ is the inspired $N_2$ partial pressure, taken as total breathing gas pressure minus $O_2$ aprtial pressure (3.1 psia in a normal atmosphere).

PEVA is the EVA total pressure.

NASA JSC Medical Science Division has agreed that R = 1.6 represents a safe value to minimize the probability of incurring the bends without prebreathing. Figure 2 shows a plot of cabin pressure to EVA pressure using this value of R. Because the existing EMU operates at 4.1 psi nominal, there is no need to use a lower EVA pressure in the future. This sets the minimum nominal cabin pressure to be considered at 9.3 psia, which is 0.2 psi higher than that planned for STS-1 EVA support.

2. Cabin Pressure Control

Figure 1 shows how the combination of minimum alveolar $PPO_2$ and maximum cabin $O_2$ concentration defines a "corner" which defines the range of allowable cabin pressures. Minimum EVA pressure, which simplifies suit mobility issues, seeks the lowest cabin pressure. The smallest cabin $PPO_2$ control and annunciation band permits the lowest cabin pressure consistent with physiological and materials limits.

Orbiter cabin pressure control (Reference 5) is shown schematically in Figure 3 There are two completely separate systems from tankage to gas inlets into the cabin. Crew-selectable cross-over valves permit interconnection modes. In each system cabin total pressure is controlled by a mechanical regulator located adjacent to middeck panel M010W, near the head. Each system has an $O_2$ partial pressure sensor, located in the aft middeck ventilation circuit duct which senses $O_2$ concentration. An $O_2/N_2$ controller, located behind panel M010W, responds to low $O_2$ concentration by closing the $N_2$ supply valve that feeds the cabin pressure regulator. Cabin pressure is thus made up with $O_2$ until the $PPO_2$ concentration is satisfied. The $O_2/N_2$ control then responds by opening the $N_2$ valve, which allows intermediate $N_2$ supply pressure at 200 $\pm$ 15 psig to supply the cabin pressure regulator. This intermediate $N_2$ pressure, upstream of the cabin pressure regulator, causes the intermediate $O_2$ supply regulator, set to 100 $\pm$ 10 psig, to close, assuring that only $N_2$ is supplied to the cabin pressure regulator.

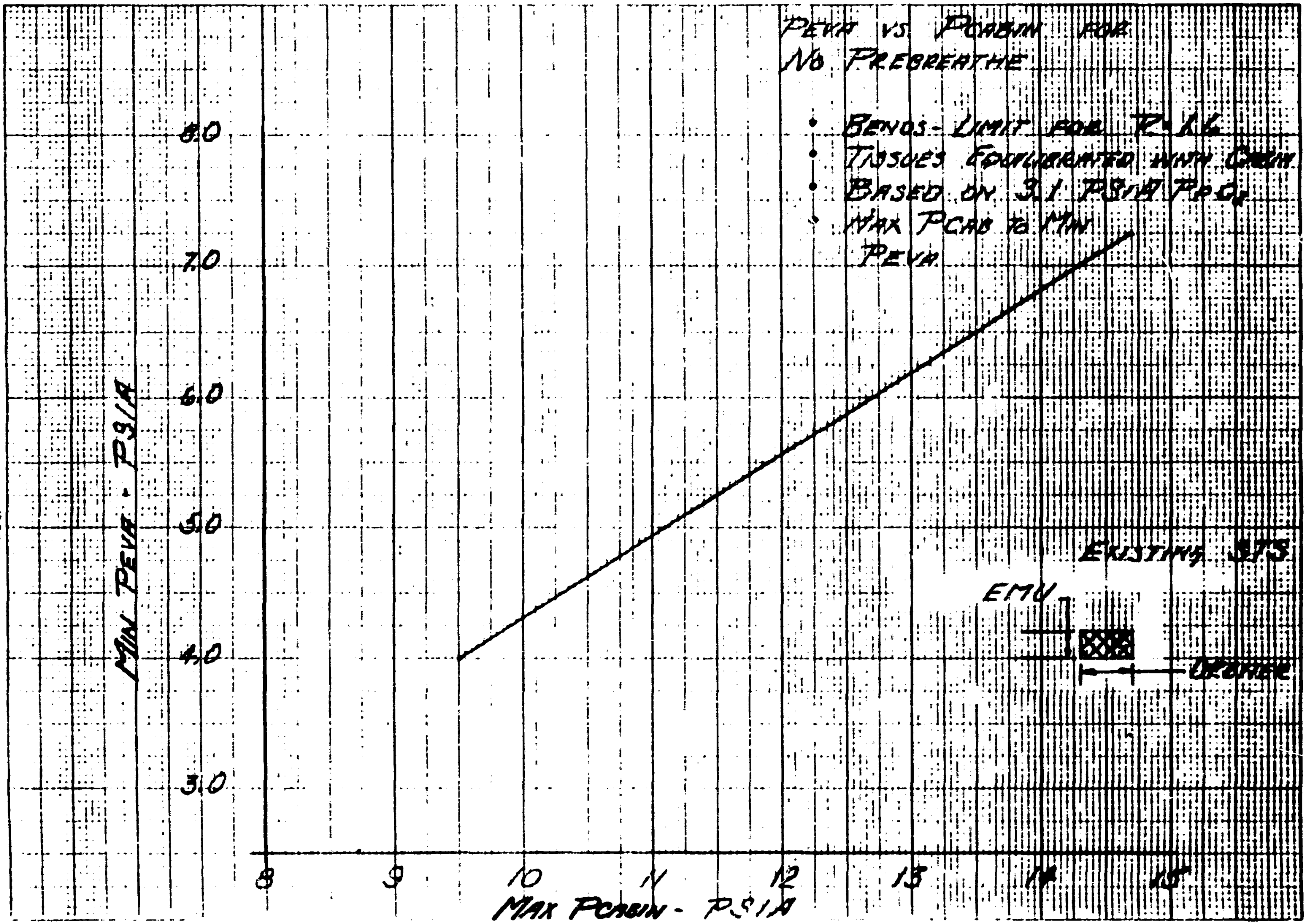


FIGURE 2

R.I.W.



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# ORBITER PRESSURE CONTROL SYSTEM

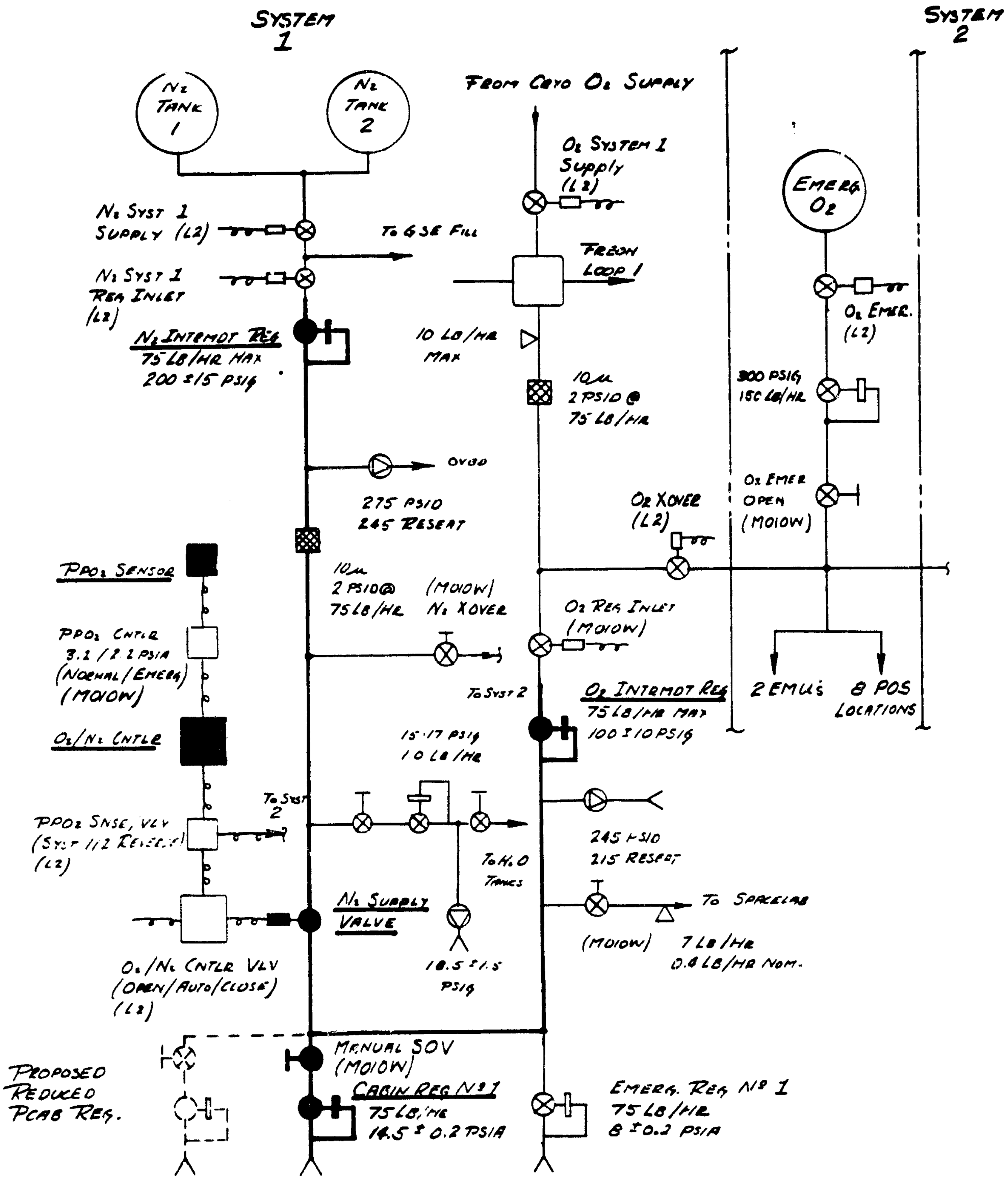


FIGURE 3



R.C.W.
6-20-81

For STS-1 total cabin pressure was set at 14.5 ± 0.2 psia. $PPO_2$ was set at 3.2 ± .25 psig with nominal C&W limits at 2.8 and 3.6 psia, as shown in Figure 1. This control band is too wide to permit significant reduction in cabin pressure to support EVA without prebreathe. Thus STS-1 baseline procedures call for manual control of cabin pressure and $PPO_2$ at lower settings to support EVA. However, safety requirements dictate use of automatic cabin pressure control for EVA support for operational flights (Reference 8).

Attachment 1 shows that the $PPO_2$ control band can be reduced to 0.33 psi using the existing cabin $O_2/N_2$ controller with lowered set point plus the new ± 1.5% $PPO_2$ sensor which is presently installed. New C & W limits would also be required. Estimated cost is $120 K (Reference 3). Revised fault detection and annunciation limits can be inputted via keyboard.

3. Relationship of Cabin Pressure to Cabin Oxygen Concentration

The following table, derived in Figure 1, shows representative achievable cabin pressures. These are based on 0.33 psi $PPO_2$ control and C&W band, and are consistent with prescribed materials and physiological $PPO_2$ limits.

| PCAB Nom. | 4k' $PPO_2$ | Max $O_2$ | PEVA | Comments |
|---|---|---|---|---|
| ± 0.2 psia | psia | % | ± 0.1 psia | Cabin total pressure and EVA pressure are the minimum... |
| 9.3 | 2.71 | 33.4 | 4.1 | ...required for consideration in this study. |
| 10.3 | 2.69 | 29.9 | 4.73 | ...at max $O_2$ % for STS-1 EVA support |
| 11.7 | 2.655 | 25.9 | 5.62 | ...at max $O_2$ % for STS-1 normal operation |
| 12.4 | 2.66 | 24.5 | 6.03 | ...at max $O_2$ % projected for Spacelab (Reference 6) |
| 12.7 | 2.65 | 23.8 | 6.14 | ...at max $O_2$% for Spacelab (Reference 4) |
| 14.7 | 2.63 | 20.7 | 7.48 | ...without changing projected STS cabin pressure |

4. Max $PPO_2$ to Materials Issues

Attachment 2 shows what steps were taken to make the Orbiter acceptable for a maximum cabin $O_2$ concentration of 25.9%. Attachment 2 also shows the results of an assessment for operation of the Orbiter cabin at 30% $O_2$ at 9 psia in support of STS-1 EVA. This evaluation required testing of 216 "major use" materials (usages over 1.0 lb and/or over 50 in$^2$). Eighty materials failed, but were subsequently accepted on the basis configuration and use as contributing to a slight but acceptable increase in flammability risk. This evaluation cost approximately $150 K, and was aided by having some material samples, piece parts and black boxes available for test.

This study identifies the potential for EVA support from a cabin at 9.1 psia minimum with $PPO_2$ at 3.04 psia, per Figure 1. This yields a maximum $O_2$ concentration of 33.4%. An evaluation similar to that of Attachment 2 would be required to identify changes to Orbiter cabin materials to support a $PPO_2$ level of 33.4%. The evaluation may be somewhat more costly if there is less material test data available at 9 psia 33% $O_2$ than at 30% $O_2$, and if some material samples and black boxes have already been used up. A summary of the types of major use materials required in a 9 psi 33% $O_2$ evaluation is contained in Attachment 3.

While an analysis of JSC-13000-5, "Flight Assignment Baseline," 12-15-80 (Reference 7) shows that there are no planned or backup EVA's on Spacelab module flights to date, it is expedient to consider supporting contingency EVA without conflicting with Spacelab material requirements. Present $O_2$ concentration limit for Spacelab is 23.8% (Reference 4), with a projected increase to 24.5% (Reference 6). Minimum nominal cabin pressures for these $O_2$ concentrations, shown in Figure 1, are 12.7 and 12.4 psia respectively. The table in the previous section shows that these cabin pressures support EVA at 6.14 and 6.03 psia nominal respectively.

5. Implementation of Two-Pressure Control

The analysis of payloads (Reference 7) identifies advantages of operating the Orbiter as a two-pressure vehicle, namely at 14.7 psia for Spacelab Module flights and at reduced cabin pressure for payload deployment flights. This could be accomplished as shown in Figure 3 by resetting the cabin pressure control to the $PPO_2$ limits shown in Figure 1 for the reduced cabin pressure selected and by controlling total cabin pressure by a third mechanical pressure regulator. A manual shut-off valve on panel M010W is required upstream of the third regulator to shut off that regulator when operating on the emergency regulator. Cost of installing a pair of regulators and shut-off valves in the vicinity of middeck panel M010W is estimated to be approximately $250 K in OV 102 and 85 K subsequently.

REFERENCES


1. Memo ECWS-PBE-01, Rev. A, "Prebreathe Elimination Study - Physiological Aspects," Richard C. Wilde, Hamilton Standard, April 1981.

2. Telecon, R. Wilde of Hamilton Standard to J. Walischauer of Carleton Controls, May 4, 1981.

3. Telecon, R. Wilde of Hamilton Standard to O. T. Stoll of Rockwell International, May 7, 1981.

4. Telecon, R. Wilde of Hamilton Standard to J. Oppenheim of Rockwell International, May 14, 1981.

5. JSC-11174, "Space Shuttle Systems Handbook OV102," Rev. A, Doc. Change 3, NASA JSC, October 6, 1980.

6. Telecon, R. Wilde of Hamilton Standard to R. N. Prince of NASA JSC, May 11, 1981.

7. Memo ECWS-PBE-02, Preliminary, "Prebreathe Elimination Study - Payload Issues," Richard C. Wilde, Hamilton Standard, May 1981.

8. Meeting with B. Miller and S. Truelock of NASA JSC NS2, March 25, 1981.

## REDUCED $PPO_2$ CONTROL BAND

1. Ground Rules (Reference 4)

- Use the same sensor to drive C&W and $O_2/N_2$ controller (Reference 3). This allows elimination of sensor-signal conditioner error from C&W band and leaves C&W error of ± 0.025 psi (± 1 bit/250 bits).
- Reduce dead bands between C&W trip and $O_2/N_2$ control from 0.41 psi to 0.01 psi (Reference 3).
- Use the new ± 1.5% $PPO_2$ sensors in place of the at 3% sensors recently replaced in OV102 (Reference 3). Error band is ± 1.5% x 5 psi = 0.15 psi.
- Use RMS to calculate $PPO_2$ sensor-controller error band (Reference 4)

| | | |
|---|---|---|
| Sensor | .15 psi | $(.15)^2 = .0225$ |
| Control | .15 psi | $(.15)^2 = \underline{.0225}$ |
| | | $(.0450)^{1/2} = 0.212$ psi |

2. Total $PPO_2$ Control Band (Reference 4)

| | | |
|---|---|---|
| C&W high limit | | 0.05 psi |
| Dead band | | 0.01 |
| Sensor-controller | | 0.21 |
| Dead band | | 0.01 |
| C&W low limit | + | 0.05 |
| | | 0.33 psi |

ATTK 'MENT - 2

Rec'd from Larry Bell
3-25 1.

## 9 PSIA/30% OXYGEN CONCENTRATION

- FOD DETERMINED THAT FOR EVA ACTIVITIES IT WOULD BE VERY DESIRABLE THAT THE CABIN BE AT 9 PSIA/30% OXYGEN FOR APPROXIMATELY 12 HOURS PRIOR TO THE EVA.
- ES5 ASKED TO EVALUATE EFFECT ON MATERIAL FLAMMABILITY
  - ES5 REVIEWED THE MATCO SYSTEM TO IDENTIFY MAJOR MATERIAL USAGES, (I.E. USAGES OVER 1 LB AND/OR 50 $IN^2$).
    - 216 MATERIALS WERE IDENTIFIED AS REQUIRING RETEST
    - ALL BLACK BOXES WERE REVIEWED/EVALUATED, TWO BLACK BOXES WERE IDENTIFIED AS REQUIRING TEST
- RESULTS OF TESTING 216 MATERIALS:
  - 80 MATERIALS FAILED
    - THE 80 MATERIALS WERE SUBSEQUENTLY EVALUATED AND IT WAS DETERMINED THAT
      - 15 CONFIGURATION TESTS WERE REQUIRED
        - ALL TESTS PASSED
      - THE REMAINING MATERIALS WERE ACCEPTABLE
        - HEAT SINK/AMOUNT OF MATERIAL
        - IGNITION SOURCE/PROXIMITY TO
        - PROPAGATION PATH
        - INSIDE BLACK BOXES
- TWO BOXES REQUIRED FLAMMABILITY TESTING:
  - "PROXIMITY SWITCH" WHICH WAS THE "WORSE CASE" EXAMPLES OF SHEET METAL, BOLTED AND VENTED CONTAINER TYPE CONSTRUCTION
  - "IMU" WHICH WAS "WORSE CASE" OF THE FORCED AIR COOLING TYPE OF BOX
  - BOTH PASSED
- BASED ON THE ABOVE THERE IS A SLIGHT INCREASE IN THE FLAMMABILITY RISK BUT IT IS ES5'S POSITION THAT FOR THE PRE-EVA CABIN DEPRESSURIZATION MODE THE RISK IS ACCEPTABLE.

- ES5 ESTIMATES THE COST FOR THE 9 PSIA EVALUATION WAS APPROXIMATELY $150K

  THIS INCLUDES:
  - MATERIAL PURCHASES
  - MATERIAL TESTING
  - COMPONENT TESTING
  - COMPONENT PROCUREMENT
    - USED AVAILABLE NONFUNCTIONAL UNITS
  - MDC TRAVEL TO RI VENDORS AND WSTF AND OVERTIME
  - RI M&P EVALUATION OF MATERIALS AND COMPONENTS
- THESE EVALUATION COSTS WERE MINIMIZED BY
  - HAVING THE "MATCO" SYSTEM TO IDENTIFY THE MATERIAL USAGES AND WHERE USED
  - MANY MATERIALS THAT REQUIRED TEST WERE AVAILABLE AT WSTF
  - THE BOXES TESTED WERE AVAILABLE TO REFURBISH
  - RI WAS ABLE TO PROVIDE CONFIGURATIONS FOR TEST FROM NONUSABLE PARTS

## 25.9% OXYGEN CONCENTRATION IN THE CABIN ATMOSPHERE

- THE CEI SPECIFICATION DEFINES THE CABIN ATMOSPHERE AS
  - TOTAL PRESSURE 14.5 ± 0.2 PSIA
  - OXYGEN PARTIAL PRESSURE 3.2 ± 0.25 PSIA (± 3% PPO₂ Sensor)
    - WORSE CASE $O_2$ CONCENTRATION IS LOWEST TOTAL PRESSURE WITH HIGHEST $O_2$ PARTIAL PRESSURE OF 23.8%

$\frac{3.4}{14.3} = 23.8\%$

- ORBITER CAUTION AND WARNING IS SET TO PROVIDE WARNING AT 3.6 $^{+0.1}_{-0.0}$ PSIA

$\frac{3.7}{14.3} = 25.9\%$

  - WORSE CASE CAUTION AND WARNING OXYGEN ATMOSPHERE IS 14.3 PSIA WITH A 3.7 PSIA $O_2$ PARTIAL PRESSURE OR 25.9% OXYGEN
- WHEN ES5 WAS INFORMED IN EARLY 1978 THAT THE 25.9% WAS WORSE CASE, THE FOLLOWING ES5 ACTIONS WERE TAKEN:
  - REVIEWED ALL ORBITER/GFE MAJOR MATERIAL USAGES IDENTIFIED IN MATCO (I.E. MATERIAL USAGES THAT EXCEEDED ONE LB.)
  - RETESTED APPROXIMATELY 150 MATERIALS
    - APPROXIMATELY 60 MATERIALS FAILED
  - ALL SUBSEQUENT TESTS WERE CONDUCTED AT 25.9% $O_2$
- AS A RESULT OF THE MATERIAL TESTS THE FOLLOWING ACTIONS WERE TAKEN
  - SEAT COVERS CHANGED TO A DOUBLE LAYER CONFIGURATION OF A FLAME RESISTANT NOMEX MATERIAL
  - ALL STOWAGE BAGS AND PROTECTIVE COVERS WERE MADE OF TWO PLY IN LIEU OF ONE PLY
  - CREW CLOTHING NOW FLAMMABLE REQUIRED A DEVIATION
  - RAYCHEM 44 WIRING IN THE ORBITER GALLEY NOW PROTECTED BY NON-FLAMMABLE OVERWRAP

ATTACHMENT 3

## Summary - Crew Compartment Major Use Materials

| Piece Parts and Associated Materials | Bulk Materials |
|---|---|
| Cushion Clamps | Charcoal |
| Edge Lit Panels | Coatings |
| Filter Materials | Fabrics |
| Gaskets and Seals | Films |
| Shims (Non-metallic) | Foams |
| Sleeving and Tubing | Inks |
| Acrylic Plexiglass | Greases and Lubes |
| Del-F | Insulated Wire and Cable |
| Lexan | Insulations |
| Nylon | Laminates |
| PCB's | Sound Insulation |
| Rulon | Sponge |
| Silicones | Velcro |
| Teflon and TFE | Webbing and Strapping |
| Viton | Varnishes |

Total: 216 Major Use Materials in Orbiter Crew Compartment

**Assembly Materials**

Adhesives

Cord and Tapes

Lacing Tape

Molding and Potting Compounds

Selants

Source: Rockwell International
Matco Report U719-10-111
10-8-80, updated 3-13-81

ECWS-PBE-04

# PREBREATHE ELIMINATION STUDY - ORBITER ECLSS CONSUMABLES

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June 1981

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MEMO HIGHLIGHTS

Title: Prebreathe Elimination Study - Orbiter ECLSS Consumables Analysis

Object of Memo:

Identify Orbiter ECLSS consumables that are sensitive to cabin pressure and to assess the resulting weight impact on the Orbiter.

Nature and Scope of Study:

This analysis is based on the STS-1 ECLSS gas budgets generated by NASA JSC Mission Planning and Analysis Division, as updated by computer modelling of the cabin puncture contingency performed by NASA JSC Crew Systems Division. This analysis is based on a 4-person 7-day payload deployment reference mission, with 2 payload support EVA's using MMU's.

Findings and Conclusions:

1. Cryo $O_2$, $GN_2$, and emergency GOX are the ECLSS consumables considered in this study.

2. Total ECLSS budgets, consisting of reserves, contingencies and flight requirements for all three atmosphere consumables, increase approximately one lb (from 437 lb to 438 lb) as cabin pressure is lowered from 14.7 to 9.3 psia nominal. Refer to Figure 1.

3. The major contributor to increased consumables use at lower cabin pressure is the flight requirement to repressurize the cabin to 14.7 psi prior to reentry (approximately 66 lb from 9.3 psia).

4. These increases are partially offset at lower cabin pressures by reductions in gas quantity required to repressurize the airlock after payload EVAs (approximately 17 lb at 9.3 psia), in cabin gas leakage (approximately 21 lb at 9.3 psia), and in the net contingency requirement to hold cabin pressure at a minimum of 8 psia for 160 minutes following a cabin puncture (approximately 27 lb).

5. Existing tankage for emergency GOX is sufficient to support operation down to 9.3 psia nominal cabin pressure.

   Existing $N_2$ tankage has a slight negative margin at all cabin pressures. The negative margin ranges between approximately 0.6% (1.6 lb) and 2.5% (6.6 lb).

   Cryo $O_2$ is allotted from the Power Reactant Supply and Distribution system. One hundred twelve pounds was allocated for STS-1. Expected Cryo $O_2$ usage ranges from approximately 109 lb at 9.3 psia cabin to 117 lb at 14.7 psia.

6. Present LiOH budgets appear acceptable for cabin pressures down to 9.3 psia nominal.

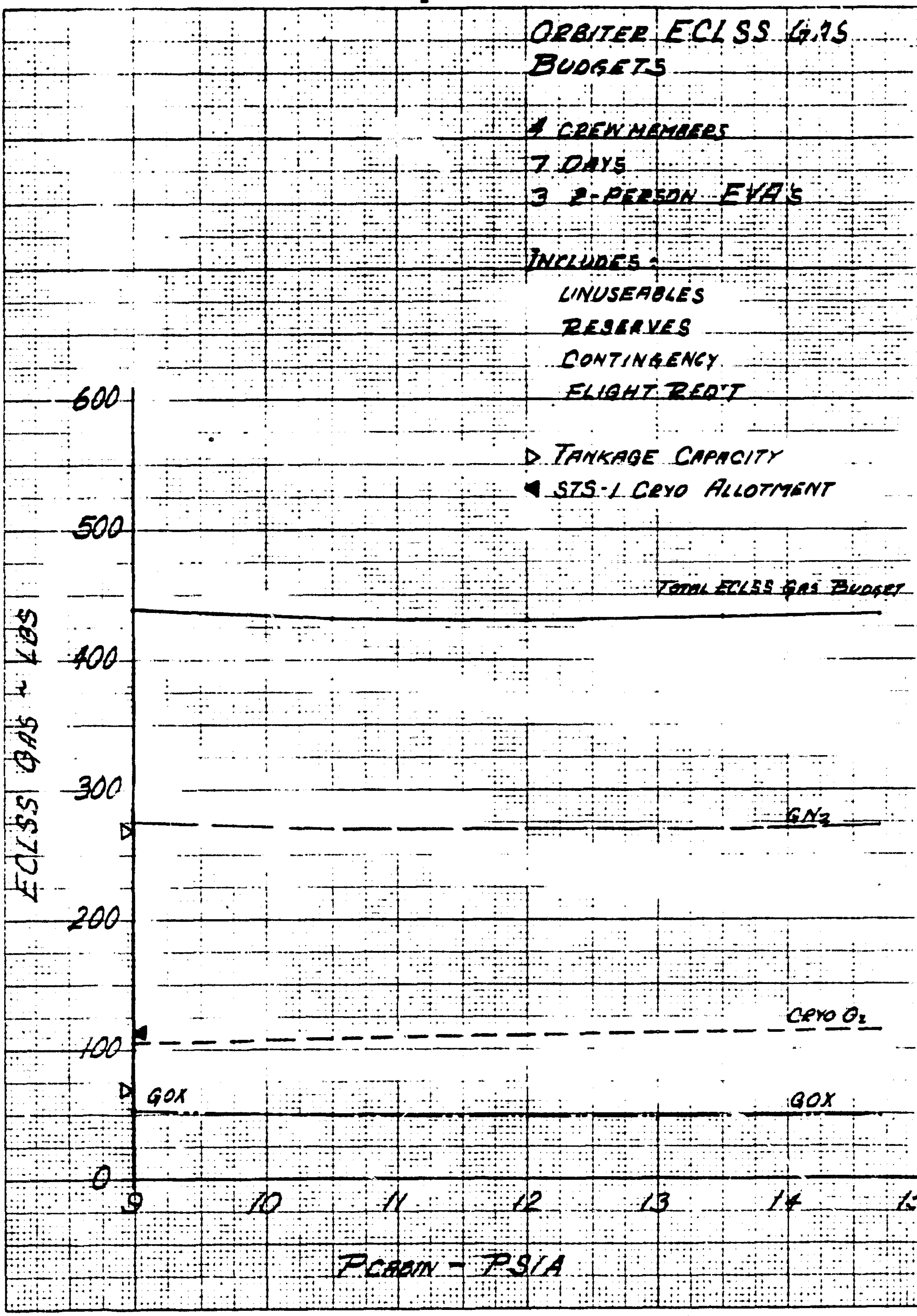



FIGURE I

6-12-81

PCW 5-21-81

Advantages of Findings and Conclusions:

- Assuming that tanks are filled completely prior to each flight, there is no significant increase due to ECLSS gas consumables down to 9 psia cabin pressure.

Disadvantages of Findings and Conclusions:

- Margins for ECLSS GOX and $GN_2$ are reduced slightly as cabin pressure is lowered, leaving less consumables available to support additional contingency requirements.
- Adherence to present mission rules may require addition of a fifth $N_2$ tank. These tanks are titanium and weigh 55 lb each. Space for a fifth tank in the mid-fuselage area may be a problem.

BACKGROUND

EVA planning for supporting STS flights calls for conducting EVA at 4.0 psia from a 14.7 psia cabin. To preclude "the bends", a painful and potentially dangerous physiological condition resulting from bubble formation when dissolved gasses in body tissues are driven out of solution by exposure to reduced ambient pressure during EVA, STS crewmembers prebreathe pure $O_2$ for 3 to 4 hours to purge body tissues of dissolved $N_2$, the prime constituent of bends bubbles. However, prebreathing has several drawbacks: the crew considers the Portable Oxygen System (POS) to restrict IVA prior to donning the EMU, and denitrogenation can be significantly reduced inadvertently during EMU donning by taking just one or two breaths of air, significantly increasing likelihood of bends, unless specific (and cumbersome) procedures are followed rigorously.

Planning for STS-1 side-steps prebreathing by requiring reduction of cabin pressure to 9 psia for approximately 12 hours prior to EVA, which promotes sufficient washout of dissolved gasses from tissues to minimize likelihood of bends. This is not a permanent solution, because it does not address many Orbiter, payload, operational, and EVA issues relevant to operational STS flights. The objective of the Prebreathe Elimination Study is to define physiologically safe EVA and cabin pressure levels while achieving an acceptable compromise between conflicting Orbiter, payload, operational, and EVA issues. This memo addresses issues involving Orbiter ECLSS consumables as a function of cabin pressure. Other issues are being addressed elsewhere in the Prebreathe Elimination Study.

PROBLEM STATEMENT

Prebreathe Elimination Study examines impacts of changing Orbiter cabin pressure and EMU EVA pressure to eliminate pure $O_2$ prebreathe prior to EVA. Because changing cabin pressure affects ECLSS atmosphere consumables usage, it is important to assess the budgets for these consumables and to determine adequacy of existing tankage.

This memo discusses key issues in atmosphere consumables budgeting, namely:

- Reference mission
- Budget analysis

## ORBITER ECLSS CONSUMABLES ISSUES

### 1. Reference Mission

Analysis of Orbiter ECLSS atmosphere consumables is based on a 4-person 7-day mission. Current flight assignment planning (Reference 6) shows this mission to combine longest duration and largest crew with payload deployment. The only flights currently planned to fly with larger crews are associated with Spacelab, for which no EVA is planned (Reference 7). A breakdown of planned flights is shown in Attachment 1.

The design reference mission draws information from STS-1 EVA planning (Reference 8), 9 psia cabin EVA support planning (Reference 1) and projected usage (Reference 5). Salient features are:

| | | | |
|---|---|---|---|
| 1. | Crew Size | 4 people | |
| 2. | Mission Duration | 7 days | |
| 3. | Cabin Pressure Profile | PCAB | Time |
| | | 14.7 psia | 0 - 8 hours |
| | | Reduced | 8 - 166 |
| | | 14.7 | 166 - 168 |
| 4. | Cabin Leakage | 8.2 lb/day @ 14.5 psia, $PPN_2$ = 11.3 psia, $PPO_2$ = 3.2 psia | |
| 5. | Cabin Volume | 2325 $ft^3$ | |
| 6. | Airlock Volume | 150 $ft^3$ | |
| 7. | Metabolic Consumption | 0.0739 lb/man-hour @ 450 Btu/hr | |
| 8. | Cabin $PPO_2$ | Nominal $PPO_2$ control point is 4000 ft alveolar equivalent (+) 0.165 psi | |
| 9. | EMU purge during donning | 0.83 lb $O_2$ | |
| 10. | EMU recharge | 1.217 lb $O_2$ | |
| 11. | MMU recharge (2 MMU's) | 40 lb $N_2$ prior to 2nd payload support EVA | |

### 2. Budget Analysis

The ECLSS gas budgets are shown in Tables 1 - 5. The table formats are based on NASA JSC MPAD's evaluation of the 9 spia cabin for STS-1 EVA support (References 1 and 2). The tables present budgets for Cryo $O_2$, emergency GOX and $GN_2$ at cabin pressures from 9.0 to 14.7 psia.

The ECLSS draws Cryo $O_2$ from tanks which are part of the Power Reactant Supply and Distribution System. Fuel cells account for over 92% of Cryo $O_2$ consumption. Hence Cryo tankage measurements and residuals are part of the PRDS budgeting, and are not chargeable to the ECLSS. For STS-1, 112 lb of Cryo $O_2$ was allocated for ECLSS use. Projected Cryo $O_2$ use for the design reference mission is approximately 117 lb at 14.7 psia and 109 lb at 9 psia cabin pressure. The chief contributor to the consumption drop at lower cabin pressures is the cabin puncture contingency which draws from the emergency GOX supply sooner at 9 psi, relieving some demand on Cryo stores.

Tables 1 - 5 use a special computer run to calculate consumables splits during the cabin puncture contingency evaluation (Reference 3). This run was tailored to the design reference mission, and shows the increase in GOX and $GN_2$ consumption required to hold cabin pressure at 8 psia as initial cabin pressure is lowered.

Emergency GOX is not seriously affected by lowering cabin pressure. Tankage margin decreases from approximately 30% (20 lbs) to 20% (14 lbs) primarily due to the cabin puncture contingency.

Tables 1 - 5 show the $GN_2$ budgets to be slightly negative for all cabin pressures. Operation with negative margin with present mission rules defining contingency provision requirements may call for adding a fifth $GN_2$ tank. These tanks are made of titanium, weight 55 lbs, and hold approximately 67 lbs of $GN_2$. They are located in the mid-fuselage area. Space for a fifth tank is at a premium (Reference 4).

The significant contributors to negative margin are the Flight Requirements for MMU recharge and cabin repressurization and the Contingency Requirement to cover cabin puncture. STS-1 mission rules permit minimizing the contingency budget by considering a cabin puncture contingency to use that portion of the Flight Requirement to repressurize the cabin backup to 14.7 psia prior to reentry. Thus the contingency budgets of $GN_2$ are net budgets for the cabin pressure cases (10.5, 12.0, and 13.5 psia) where net cabin puncture usage is the largest line item in the $GN_2$ contingency budget.

Different situations exist at 9.0 and 14.7 psia cabins. The $GN_2$ contingency budget at 9.0 psia consists of the repress line item from 8 to 14.7 psia, because that line item (66.7 lb) exceeds the net cabin puncture line item (133.1 - 66.7 = 66.33 lb). The 14.7 psia $GN_2$ contingency is not a net budget, because the flight repressurization allowance is zero.

Figure 1 shows plots of Cryo $O_2$, GOX, and $GN_2$. The plots for all three ECLSS consumables are essentially independent of cabin pressure. The figure also shows the weight total for the three consumables. The total net change is composed of offsetting effects which are significantly sensitive to cabin pressure, as shown in the following tabulation.

| PCAB, psia | 9.0 | 14.7 | Net Change |
|---|---|---|---|
| Dispersion allowance | 22.94 lb | 20.05 lb | 2.89 lb |
| Net cabin puncture contingency | 125.72 | 152.4 | -26.68 |
| Net line items for other worst case contingencies | 1.37 ($GN_2$) | 5.54 (GOX) | -4.17 |
| Cabin leakage | 86.97 | 104.68 | -20.71 |
| A/L repress (flight req't only) | 36.01 | 52.81 | -16.8 |
| Cabin repress | 66.77 | 0 | 66.77 |
| | 339.78 lb | 338.48 lb | 1.3 lb |

Test evaluation of LiOH performance at JSC indicates no significant loss of performance at cabin pressures down to 9.0 psia (Reference 9). Thus LiOH impacts need not be considered further in this study.

## REFERENCES


1. JSC 16730, "ECLSS Analysis of STS-1, 9 Psia EVA Configuration," G. J. Steines, McDonnell Douglas Technical Services Co., for NASA JSC MPAD, July 1980.

2. Meeting with G. J. Steines of McDonnell Douglas Technical Services Co., March 24, 1981.

3. Computer Run "Commander II" dated March 26, 1981, 9:40 a.m. by Sharon Lafuse, NASA JSC EC2.

4. Telecon with J. Oppenheim of Rockwell International, May 21, 1981.

5. Telecon with Ed Whitsett of NASA JSC EC5, May 22, 1981.

6. JSC 13000-5, "STS Flight Assignment Baseline", STS Operations - NASA Headquarters, December 15, 1980.

7. Memo ECWS-PBE-02 Preliminary, "Prebreathe Elimination Study - Payload Issues," Richard C. Wilde, Hamilton Standard, May 1981.

8. JSC 12813 Basic, "STS-1 Flight Data File EVA Operations Book," NASA JSC, January 2, 1981.

9. Memo Analysis 81-24, "Shuttle - Results of 9.0 psia LiOH Testing at JSC," A. Decrisantis, Hamilton Standard, February 2, 1981.

10. Telecon with G. J. Steines of McDonnell Douglas Technical Services Co., June 3, 1981.

TABLE 1

ECLSS Atmosphere Gas Budget, 9.0 Psia Cabin

| | Cryo $O_2$[1] | | Aux $O_2$ | GOX | $GN_2$ | |
|---|---|---|---|---|---|---|
| • Total Loaded, Lb Nom. (Ref. 4) | N/A | | | 67.6 | | 268.6 |
| • Unusables: Residual | N/A | | 11.0 | | 26.0 | |
| • Reserves (Ref. 1) | | | | | | |
| Measurement Error | N/A | | 5.0 | | 16.2 | |
| Dispersion Allowance (10% Flt. Req't) | 7.94 | | 0 | | 15.0 | |
| SUBTOTAL | | 7.94 | | 16.0 | | 57.2 |
| • Contingency | | | | | | |
| MMU Recharge (2 MMU's) (Ref. 5) | 0 | | 0 | | 40.0 | |
| 1-Day Extension at 14.7 psia | 8.85 | | 0 | | 6.52 | |
| Cabin Puncture (Ref. 3) | 21.65 | | 37.74 | | 133.10 | |
| Single Cabin Repress to 8 psia | 0 | | 31.44 | | 64.25 | |
| Single Cabin Repress 8 - 14.7 psia | 0 | | 10.49 | | 67.70 | |
| 1 x 2-person EVA @ PCAB | 8.76 | | 0 | | 9.24 | |
| SUBTOTAL [2] | | 21.65 | | 37.74 | | 67.70 |
| • Flight Requirement | | | | | | |
| MMU Recharge (2 MMU's) | 0 | | 0 | | 40.0 | |
| Leakage and Metabolic | 61.87 | | 0 | | 25.10 | |
| 2 x 2-person EVAs @ PCAB | 17.53 | | 0 | | 18.48 | |
| Cabin Repress PCAB - 14.7 psia | 0 | | 0 | | 66.77 | |
| SUBTOTAL | | 79.40 | | 0 | | 150.35 |
| TOTAL CONSUMABLE USE | | 108.99 | | 53.74 | | 275.25 |
| • Margin, Lb Nom. | N/A | | 13.86 | | (-) 6.65 | |

1 Allotted from PSRD Budget

2 Consists of Worst Contingency Only, i.e., single Cabin Repress 8 to 14.7 psia, which exceeds Cabin Puncture (-) Repress from 9.0 to 14.7 psia.

## TABLE 2

## ECLSS Atmosphere Gas Budget, 10.5 Psia Cabin

| | Cryo $O_2$[1] | | Aux $O_2$ | GOX | $GN_2$ | |
|---|---|---|---|---|---|---|
| • Total Loaded, Lb Nom. (Ref. 4) | | N/A | | 67.6 | | 268.6 |
| • Unusables: Residual | N/A | | 11.0 | | 26.0 | |
| • Reserves (Ref. 1) | | | | | | |
| Measurement Error | N/A | | 5.0 | | 16.2 | |
| Dispersion Allowance (10% Flt. Req't) | 7.89 | | 0 | | 14.3 | |
| SUBTOTAL | | 7.89 | | 16.0 | | 56.5 |
| • Contingency | | | | | | |
| MMU Recharge (2 MMU's) (Ref. 5) | 0 | | 0 | | 40.0 | |
| 1-Day Extension at 14.7 psia | 8.85 | | 0 | | 6.52 | |
| Cabin Puncture (Ref. 3) | 24.89 | | 34.16 | | 120.20 | |
| Single Cabin Repress to 8 psia | 0 | | 31.44 | | 64.25 | |
| Single Cabin Repress 8 - 14.7 psia | 0 | | 10.49 | | 67.70 | |
| 1 x 2-person EVA @ PCAB | ___ | | 0 | | ___ | |
| SUBTOTAL[2] | | 24.89 | | 34.16 | | 71.32 Net |
| • Flight Requirement | | | | | | |
| MMU Recharge (2 MMU's) | 0 | | 0 | | 40.0 | |
| Leakage and Metabolic | 61.63 | | 0 | | 30.92 | |
| 2 x 2-person EVAs @ PCAB | 17.31 | | 0 | | 23.10 | |
| Cabin Repress PCAB - 14.7 psia | 0 | | 0 | | 48.88 | |
| SUBTOTAL | | 78.94 | | 0 | | 142.90 |
| TOTAL CONSUMABLE USE | | 111.72 | | 50.16 | | 270.72 |
| • Margin, Lb Nom. | N/A | | 17.44 | | (-) 2.12 | |

1 Unuseables and Measurement Errors in PRSD Budget

2 Consists of Worst Contingency Only, i.e., Cabin Puncture (-) Repress from 10.5 to 14.7 psia

## TABLE 3

### ECLSS Atmosphere Gas Budget, 12.0 Psia Cabin

| | Cryo $O_2$ [1] | | Aux $O_2$ | GOX | $GN_2$ | |
|---|---|---|---|---|---|---|
| • Total Loaded, Lb Nom. (Ref. 4) | | N/A | | 67.6 | | 268.6 |
| • Unusables: Residual | N/A | | 11.0 | | 26.0 | |
| • Reserves | | | | | | |
| Measurement Error | N/A | | 5.0 | | 16.2 | |
| Dispersion Allowance (10% Flt. Req't) | 7.88 | | 0 | | 13.5 | |
| SUBTOTAL | | 7.88 | | 16.0 | | 55.7 |
| • Contingency | | | | | | |
| MMU Recharge (2 MMU's) (Ref. 5) | 0 | | 0 | | 40.0 | |
| 1-Day Extension at 14.7 psia | 8.85 | | 0 | | 6.52 | |
| Cabin Puncture (Ref. 3) | 27.35 | | 30.00 | | 110.44 | |
| Single Cabin Repress to 8 psia | 0 | | 31.44 | | 64.25 | |
| Single Cabin Repress 8 - 14.7 psia | 0 | | 10.49 | | 67.70 | |
| 1 x 2-person EVA @ PCAB | 8.62 | | 0 | | 13.80 | |
| SUBTOTAL [2] | | 27.35 | | 31.44 | | 79.0 Net |
| • Flight Requirement | | | | | | |
| MMU Recharge (2 MMU's) | 0 | | 0 | | 40.0 | |
| Leakage and Metabolic | 61.54 | | 0 | | 36.40 | |
| 2 x 2-person EVAs @ PCAB | 14.25 | | 0 | | 27.60 | |
| Cabin Repress PCAB - 14.7 psia | 0 | | 0 | | 31.44 | |
| SUBTOTAL | | 78.79 | | 0 | | 135.44 |
| TOTAL CONSUMABLE USE | | 114.02 | | 47.44 | | 270.14 |
| • Margin, Lb Nom. | N/A | | 20.16 | | (-) 1.54 | |

1 Unusables and Measurement Errors in PRSD Budget

2 Consists of Worst Contingency Only, i.e., Cabin Puncture (-) Repress from 12.0 to 14.7 psia

## TABLE 4

### ECLSS Atmosphere Gas Budget, 13.5 Psia Cabin

| | Cryo $O_2$ [1] | | Aux $O_2$ | GOX | $GN_2$ | |
|---|---|---|---|---|---|---|
| • Total Loaded, Lb Nom. (Ref. 4) | | N/A | | 67.6 | | 268.6 |
| • Unuseables: Residual | N/A | | 11.0 | | 26.0 | |
| • Reserves (Ref. 1) | | | | | | |
| Measurement Error | N/A | | 5.0 | | 16.2 | |
| Dispersion Allowance (10% Flt. Reqt.) | 7.87 | | 0 | | 12.8 | |
| SUBTOTAL | | 7.87 | | 16.0 | | 55.0 |
| • Contingency | | | | | | |
| MMU Recharge (2 MMU's) (Ref. 5) | 0 | | 0 | | 40.0 | |
| 1-Day Extension at 14.7 psia | 8.85 | | 0 | | 6.52 | |
| Cabin Puncture (Ref. 3) | 29.50 | | 26.33 | | 101.75 | |
| Single Cabin Repress to 8 psia | 0 | | 31.44 | | 64.25 | |
| Single Cabin Repress 8 - 14.7 psia | 0 | | 10.49 | | 67.70 | |
| 1 x 2-person EVA @ PCAB | 8.85 | | 0 | | 16.05 | |
| SUBTOTAL [2] | | 29.50 | | 31.44 | | 87.75 Net |
| • Flight Requirement | | | | | | |
| MMU Recharge (2 MMU's) | 0 | | 0 | | 40.0 | |
| Leakage and Metabolic | 61.46 | | 0 | | 41.89 | |
| 2 x 2-person EVAs @ PCAB | 17.19 | | 0 | | 32.10 | |
| Cabin Repress PCAB - 14.7 psia | 0 | | 0 | | 14.00 | |
| SUBTOTAL | | 78.65 | | 0 | | 127.99 |
| TOTAL CONSUMABLE USE | | 116.02 | | 47.44 | | 270.74 |
| • Margin, Lb Nom. | N/A | | 20.16 | | (-) 2.14 | |

1 Unusables and Measurement Errors in PRSD Budget

2 Consists of Worst Contingency Only, i.e., Cabin Puncture

(-) Repress from 13.5 to 14.7 psia

**TABLE 5**

**ECLSS Atmosphere Gas Budget, 14.7 Psia Cabin**

| | Cryo $O_2$ [1] | | Aux $O_2$ | GOX | $GN_2$ | |
|---|---|---|---|---|---|---|
| • Total Loaded, Lb Nom. (Ref. 4) | | N/A | | 67.6 | | 268.6 |
| • Unusables: Residual | N/A | | 11.0 | | 26.0 | |
| • Reserves (Ref. 1) | | | | | | |
| Measurement Error | N/A | | 5.0 | | 16.2 | |
| Dispersion Allowance (10% Flt. Req't) | 7.85 | | 0 | | 12.2 | |
| SUBTOTAL | | 7.85 | | 16.0 | | 54.4 |
| • Contingency | | | | | | |
| MMU Recharge (2 MMU's) (Ref. 5) | 0 | | 0 | | 40.0 | |
| 1-Day Extension at 14.7 psia | 8.85 | | 0 | | 6.52 | |
| Cabin Puncture (Ref. 3) | 31.00 | | 25.90 | | 95.50 | |
| Single Cabin Repress to 8 psia | 0 | | 31.44 | | 64.25 | |
| Single Cabin Repress 8 - 14.7 psia | 0 | | 10.49 | | 67.70 | |
| 1 x 2-person EVA @ PCAB | 8.55 | | 0 | | 17.85 | |
| SUBTOTAL [2] | | 31.00 | | 31.44 | | 95.50 |
| • Flight Requirement | | | | | | |
| MMU Recharge (2 MMU's) | 0 | | 0 | | 40.0 | |
| Leakage and Metabolic | 61.38 | | 0 | | 46.30 | |
| 2 x 2-person EVAs @ PCAB | 17.11 | | 0 | | 35.70 | |
| Cabin Repress PCAB - 14.7 psia | 0 | | 0 | | 0 | |
| SUBTOTAL | | 78.49 | | 0 | | 122.00 |
| TOTAL CONSUMABLE USE | | 117.34 | | 47.44 | | 271.9 |
| • Margin, Lb Nom. | N/A | | 20.16 | | (-) 3.3 | |

1 Unusables and Measurement Errors in PRSD Budget

2 Includes Worst Contingency Only

ATTACHMENT 1

## Breakdown of Planned STS Flights
(Reference 6)

| | | | |
|---|---|---|---|
| Flights identified to date | | | 79 |
| Flights without duration and crew size information | | | |
| | - DOD | 18 | |
| | - Reflights and payloads of opportunity | 10 | -28 |
| Flights with available crew size and duration information | | | 51 |

| Crew Size | Duration - Days 1 | 2 | 3 | 5 | 7 | |
|---|---|---|---|---|---|---|
| 2 | 4 | 3 | 1 | 1 | 2 | 11 |
| 3 | - | - | 6 | 9 | 4 | 19 |
| 4 | - | - | - | - | 5 | 5 |
| 6 | - | - | - | - | 16 [1] | 16 |
| | | | | | | 51 Total |

1 - All Spacelab module flights plus S/L D 4. No Planned EVA.

# PREBREATHE ELIMINATION STUDY - AIR-COOLED AVIONICS

Gordon Allen
System Analyst
Advanced EVA Studies

R. C. Wilde

Approved: R. C. Wilde
Engineering Manager
Advanced EVA Studies

July 1981

Hamilton Standard Division
United Technologies Corporation

MEMO HIGHLIGHTS

Title: Prebreathe Elimination Study - Air-Cooled Avionics

Objective of Study: Evaluate the adequacy of the Orbiter Atmospheric Revitalization Subsystem (ARS) to provide cooling of air-cooled avionic equipment under reduced cabin pressure.

Findings and Conclusions:

1. Operation of the cabin at 11.6 psia is feasible if the following air-cooled avaionics load management is implemented.

   - Some load redistribution is required between avionics bays 1 and 3.

   - Operation at reduced cabin pressures requires that one out of the three IMU be powered down.

2. Powering down of select flight deck avionics and running 2 cabin fans may be required if:

   - the crew size exceeds 4 people
   - solar exposure exceeds nominal
   - avionic box as-designed wall temperature exceeds 170°F.

3. Power-down requirements do not exceed those planned for STS-1 priority power-downs 1 - 3.

Nature and Scope of Study:

Adequate cooling will be provided if air temperature leaving the avionics is below 130°F at 14.7 psia. Analysis was performed to determine air exit temperatures of avionic equipment located in the cabin and in the three avionic bays as a function of crew size, cabin pressure, ARS performance, solar orientation and electrical equipment operation.

Advantage of Findings:

Reconfiguration of air-cooled avionics loads does not have any meaningful impact on Orbiter on-orbit capability.

Disadvantage of Findings:

Operating 2 fans on a regular basis may require more frequent fan change-out.

## BACKGROUND

EVA planning for supporting STS flights calls for conducting EVA at 4.0 psia from a 14.7 psia cabin. To preclude "the bends", a painful and potentially dangerous physiological condition resulting from bubble formation when dissolved gasses in body tissues are driven out of solution by exposure to reduced ambient pressure during EVA, STS crewmembers prebreathe pure $O_2$ for 3 to 4 hours to purge body tissues of dissolved $N_2$, the prime constituent of bends bubbles. However, prebreathing has several drawbacks: the crew considers the Portable Oxygen System (POS) to restrict IVA prior to donning the EMU; and denitrogenation can be significantly reduced inadvertently during EMU donning by taking just one or two breaths of air, significantly increasing likelhood of bends, unless specific (and cumbersome) procedures are followed rigorously.

Planning for STS-1 side-stepped prebreathing by requiring reduction of cabin pressure to 9 psia for approximately 12 hours prior to EVA, which promotes sufficient washout of dissolved gasses from tissues to minimize likelihood of bends. This is not a permanent solution, because it does not address many Orbiter, payload, operational, and EVA issues relevant to operational STS flights. The objective of the Prereathe Elimination Study is to define physiologically safe EVA and cabin pressure levels while achieving an acceptable compromise between conflicting Orbiter, payload, operational and EVA issues. This analysis was conducted to evaluate the adequacy of the ARS to cool the avionics at reduced cabin pressures.

## PROBLEM STATEMENT

Prebreathe Elimination Study examines impacts of changing Orbiter cabin pressure and EMU EVA pressure to eliminate pure $O_2$ prebreathe prior to EVA. However, reducing cabin pressure to support EVA impacts the air-cooled avionics in two ways. One, it reduces the total mass flow and thus the cooling capacity of the air. Two, it reduces the ability to transfer heat between the avionics and the air. This analysis establishes the cooling capacity of the air as a function of cabin pressure and identifies and evaluates air-cooled avionics load management approaches to permit cabin pressure reduction.

## SYSTEM DEFINITION

### ARS

The ARS comprises a water loop and five air loops (Figure 1). The air loops provide cooling for personnel and equipment and transport heat to the water loop via heat exchangers. The forced air-cooled avionics are manifolded in parallel (Reference 4) to draw cool avionics bay or cabin air through each device. The amount of air flow for each device is set by orifice to produce a uniform temperature rise. Under normal conditions the temperature rise is 35°, 30°, and 17°F for devices located in the cabin (both Flight Deck Avionics and IMU), Avionics Bays 1 and 2, and Avionics Bay 3, respectively. The water loop provides cold plate cooling and transports this heat plus heat from the air loop heat exchangers to the Interchanger Heat Exchanger (I/C HEX). The I/C HEX transfers the heat to the Freon Coolant Loop. System operating conditions are itemized below and are as specified by Reference 1, except where noted.

### Water Loop

- No water bypass (chosen for maximum cooling configuration)
- Water Pump Flow; 1250 pph (Reference 2)
- Water Pump Heat Load; 1160 Btu/hr. (Reference 7)
- Avionics Bay Water Flow; (Reference 2)
  - a. Bay One; 302 pph
  - b. Bay Two; 300 pph
  - c. Bay Three A; 591 pph
  - d. Bay Three B; 57 pph
- I/C HEX Effectiveness; .745 (minimum)/.76 (nominal)
- I/C HEX Freon Inlet Temperature; 40°F (maximum)/38°F (nominal)

### Flight Deck

- No air bypass (chosen for maximum cooling configuration)
- Fan Flow;
  - a. Minimum; 305 CFM (one fan)/336 CFM (two fans)
  - b. Nominal; 340 CFM (one fan)/375 CFM (two fans)
- Fan Heat Load; 1665 Btu/hr/fan (Reference 8)
- Condenser UA; 0.558 x (effective air flow in pph) + 125.0

### IMU

- Fan Flow; 34 CFM
- Fan Heat Load; 167 Btu/hr (Reference 8)
- IMU HEX effectiveness; 1.053 - .002 x (air flow in pph)

## Avionics Bays

- Fan Heat Load; 584 Btu/hr/fan (Reference 8)
- Fan Flow Bay 1; 195 CFM (one fan)/206 CFM (two fans)
- Fan Flow Bay 2; 196 CFM (one fan)/209 CFM (two fans)
- Fan Flow Bay 3; 172 CFM (one fan)/175 CFM (two fans)
- HEX Air Exit Temperature; (Reference 7)

  T = Water Inlet Temperature + (constant #1)x(air flow in pph) + constant #2

  where: constant #1 = .0035(Bay 1)/.0025(Bay 2)/ .00075(Bay 3 nominal)/.0028(Bay 3)

  constant #2 = 11.8(Bay 1)/6.0(Bay 2)/0.4(Bay 3 nominal)/ 1.75(Bay 3)

## Heat Loads

- Metabolic (assumes 65°F cabin for calculating sensible/latent split)
  - a. Sensible; 2639 Btu/hr (7 men)/1509 Btu/hr (4 men)
  - b. Latent; 1524 Btu/hr (7 men)/575 Btu/hr (4 men)
- Lithium Hydroxide (LiOH)
  - a. Sensible; 714 Btu/hr (7 men)/ 357 Btu/hr (4 men)
  - b. Latent; 347 Btu/hr (7 men)/174 Btu/hr (4 men)
- Heat Leaks
  - a. Wall to Cabin; 1723 Btu/hr (maximum)/44 Btu/hr (nominal)
  - b. Bays to Cabin; 297 Btu/hr (maximum)/186 Btu/hr (nominal)
  - c. Wall to Water Loop; 867 Btu/hr (maximum)/-356 Btu/hr (nominal)
- Cabin Electrical (Reference Appendix I - Table I)
  - a. Maximum; 4312 Btu/hr
  - b. Minmum; 609 Btu/hr (Power down)
- Flight Deck Avionics (Reference Appendix I - Table I)
  - a. Maximum; 8530 Btu/hr (7 men)/6711 Btu/hr (4 men)
  - b. Minimum; 2896 Btu/hr (Power down)
- IMU (Reference Appendix I - Table II)
  - a. Nominal; 1290 Btu/hr (3 units)
  - b. Proposed; 860 Btu/hr (2 units)
- Avionics Bay 1 (Reference Appendix I - Tables III and VI)
  - a. Air-Cooled Avionics; 5128 Btu/hr(max)/2636 Btu/hr(proposed)
  - b. Cold Plate Avionics; 5640 Btu/hr
- Avionics Bay 2 (Reference Appendix I - Tables IV and VI)
  - a. Air-Cooled Avionics; 2616 Btu/hr (nominal)
  - b. Cold Plate Avionics; 6051 Btu/hr
- Avionics Bay 3 (Reference Appendix I - Tables V and VI)
  - a. MDM; 177 Btu/hr
  - b. Air-Cooled Avionics; 2741 Btu/hr(proposed)/250 Btu/hr(min)
  - c. Bay 3A Cold Plates; 8277 Btu/hr
  - d. Bay 3B Cold Plates; 990 Btu/hr

ANALYSIS

## Crew Size

Reference 5 indicates that all the planned and backup EVA flights have crews of 2 and 3, and nearly all (70%) of the known flights have crews of 4 or less (Table I). Since the crew size has a big impact on the cabin temperature and subsequently on the Flight Deck Avionics, this analysis considers the ARS cooling capacity for both a 7-man crew and a 4-man crew.

## Cooling Requirement

The avionics equipment is designed to operate satisfactorily as long as the cooling air exit temperature is maintained below 130°F at 14.7 psia (Reference 4). By reworking the expression for heat transfer and the coefficient of forced convection, a relationship for the maximum allowable air temperature as a function of cabin pressure, air velocity and avionic wall temperature was developed (Appendix II). The exact wall temperature used in designing the cooling system is unknown. However, a maximum component temperature of 150°C (302°F) was used during vacuum (no cooling) tests. Current commercial practice establishes a minimum temperature difference between a component and its heat sink of 80°F (220°F wall temperature). This is a maximum wall temperature, and in practice a wall temperature somewhere between this and the air temperature of 130°F is expected.

For reference purposes, a wall temperature of 170°F has been assumed in addition to the 220°F. The 170°F is significant because at 11.6 psia it is consistent with the 7-man cooling requirement (Figure 5). The 11.6 psia pressure level has been previously determined to be the minimum permissible pressure level (Reference 9). The effect of wall temperature and pressure on the maximum air temperature is presented on Figure 2.

Based on the specified maximum and minimum values for cabin and avionic bay fans given in Reference 1, it appears that the air velocity within the cabin avionics can vary ± 10% and within the avionics bays, 5%. The -10% results from a single cabin fan performance of 305 CFM and the +10% results from a two-fan performance of 375 CFM. The -5% results from a single avionics bay performance of 195 CFM. The impact of air velocity and pressure on the maximum air temperature is presented on Figure 3.

## Air Exit Temperature

Reference 1 specifies the operating conditions which would result in the maximum impact of external and internal heat loads. These conditions are minimum I/C HEX effectiveness, maximum I/C HEX Freon inlet temperature, minimum cabin fan flow and maximum heat leaks. For this configuration the effects on flight deck avionic air exit temperatures were determined for both 4- and 7-man expected heat loads. The results are presented on Figure 4. This curve shows that there is no margin to handle the maximum impact of heat loads at less than 14.7 psia, the Orbiter cabin design point. Figure 5 shows the cooling margin that can be created by powering down select flight deck heat loads to accommodate the maximum impacts of heat loads at reduced cabin pressures. Figures 6 and 6A show the cooling margin that exists with nominal impact of external and internal heat loads at reduced cabin pressures, operating one and two cabin fans. Figures 7 - 11 show similar margins for the IMU's and air-cooled equipment in Avionics Bays 1 - 3.

Several approaches to improve cooling margin were analyzed. They included powering down one IMU (Figure 8), operating two fans in Avionics Bay 1 (Figure 11A), and shifting operation from one of the two General Purpose Computers (GPC) being used in Bay 1 to the GPC in Bay 3 (Figures 11 and 12).

## RESULTS

### Crew Size

Current planning indicates that the crew size on planned and backup EVA flights will be 2 or 3 (Table I). Hence analysis based on 4 crew members is conservative. Current planning for flights with contingency EVA indicates that the crew size will not exceed 6. Hence anlaysis based on 7 crew members is also conservative.

### Cooling Requirements

The allowable maximum air temperature is a function of both cabin pressure and avionic box wall temperature (Figure 2).

### Fan Performance

Increasing air velocity through the avionic boxes by operating additional fans will increase the allowable maximum air exit temperature. Conversely, degraded fan performance will reduce the allowable air exit temperature (Figure 3).

### Minimum Cooling Margin

With the ARS operating at conditions designed to maximize the effect of heat loads, i.e., minimum air flow, maximum Freon coolant temperature and minimum I/C HEX effectiveness, and with maximum expected heat loads (7-man crew, maximum solar orientation and maximum amount of avionics operating), there is no excess cooling capability at 14.7 psia (Figure 4). This confirms the validity of the ARS sizing for worst case sea level cabin conditions.

## Maximum Cooling Margin

Additional cooling margin to support operation at reduced cabin pressures can be obtained at the above conditions by partial power-down of some Flight Deck Avionics and operating both cabin fans (Figure 5). This is approximately the same margin provided by the ARS operating at nominal conditions (nominal air flow, Freon coolant temperature and I/C HEX effectiveness) and nominal heat loads asociated with a 4-man crew (Figure 6) or if two cabin fans are operating with a 7-man crew (Figure 6A).

## IMU Cooling Margin

IMU cooling margin is less than the 7-man partial power-down flight deck case (Figure 7). The cooling margin can be made to approximate that of flight deck by powering down one of the IMU's (Figure 8).

## Avionics Bay Cooling Margin

Under the present distribution of air-cooled avionics loads, Avionics Bay One has less and Bay Three has more cooling margin than the Flight Deck (Figures 9 and 10). By operating one GPC in each bay (total of 3) instead of two in Bay One and one in Bay Two (total of 3), the cooling margin of each bay can be equalized with that of Flight Deck (Figures 11 and 12). If both computers in Bay One must be operated, the cooling margin can still be made approximately equal to the Flight Deck be operating two fans (Figure 11A).

## Conclusion

Assuming that the sea level avionic wall temperature as designed is 170°F or less and with use of select procedures, adequate avionics cooling can be obtained down to a cabin pressure of 11.8 psia nominal/11.6 psia minimum.

## Recommendation

Flights with planned or backup EVA's should be limited to 4 or less crewmen. The will permit full avionics operaton under nominal system conditions with nominal external heat loads.

## REFERENCES


1. "Orbiter ECLSS Characteristic Data for OV 102 and Subsequent Vehicles," Effective March 31, 1978, EC2/J. R. Jaax.

2. "Environmental Control and Life Support Systems Analysis of STS-1," "9 psi Extravehicular Activity Configuration"; by the Mission Planning and Analysis Division of NASA, dated July 1980, Document Numbers JSC 16730 and 80-FM-36.

3. "Proposed On-Orbit Avionics Configuration STS-2,3,4 For Nominal and FTO-Unique Activities", CAG/G. J. Harbaugh, June 20, 1980.

4. NASA Memorandum on "Air Cooling," CA5/Chief T. W. Holloway, December 10, 1980, Document No. CA5-80-76.

5. "Prebreathe Elimination Study - Payload Issues," by Richard C. Wilde, Hamilton Standard, May 1981, Document No. ECWS-PBE-02.

6. Drawing 6.2, Atmospheric Circulation System of "Space Shuttle Handbook for Orbital Vehicle 102," Rev. A., Document Change 3, October 6, 1980, Document No. JSC 11174.

7. "Shuttle Atmospheric Revitalization Subsystem Critical Design Review for Vehicle 102," September 29, 1976.

8. Telecons with Mr. J. Chambliss of McDonnell Douglas Technical Services Co., January - June 1981.

9. "Prebreathe Elimination Study - Cabin Pressure and Materials Issues," R. C. Wilde, Hamilton Standard, May 1981, Document No. ECWS-PBE-03.

## TABLE I
## CREW SIZE

| CREW SIZE | NUMBER OF FLIGHTS | TYPE EVA PLANNED |
|---|---|---|
| 2 | 11 | 2 - PLANNED<br>6 - BACKUP<br>3 - CONTINGENCY |
| 3 | 19 | 3 - BACKUP<br>14 - CONTINGENCY<br>2 - TBD |
| 4 | 5 | 3 - CONTINGENCY<br>2 - TBD |
| 6 | 16 | 16 - CONTINGENCY |
| TBD | 28 | TBD |
| TOTAL | 79 | |

Planned - EVA is the baseline mode for accomplishing mission objectives. Mission support equipment is designed for operation by EVA.

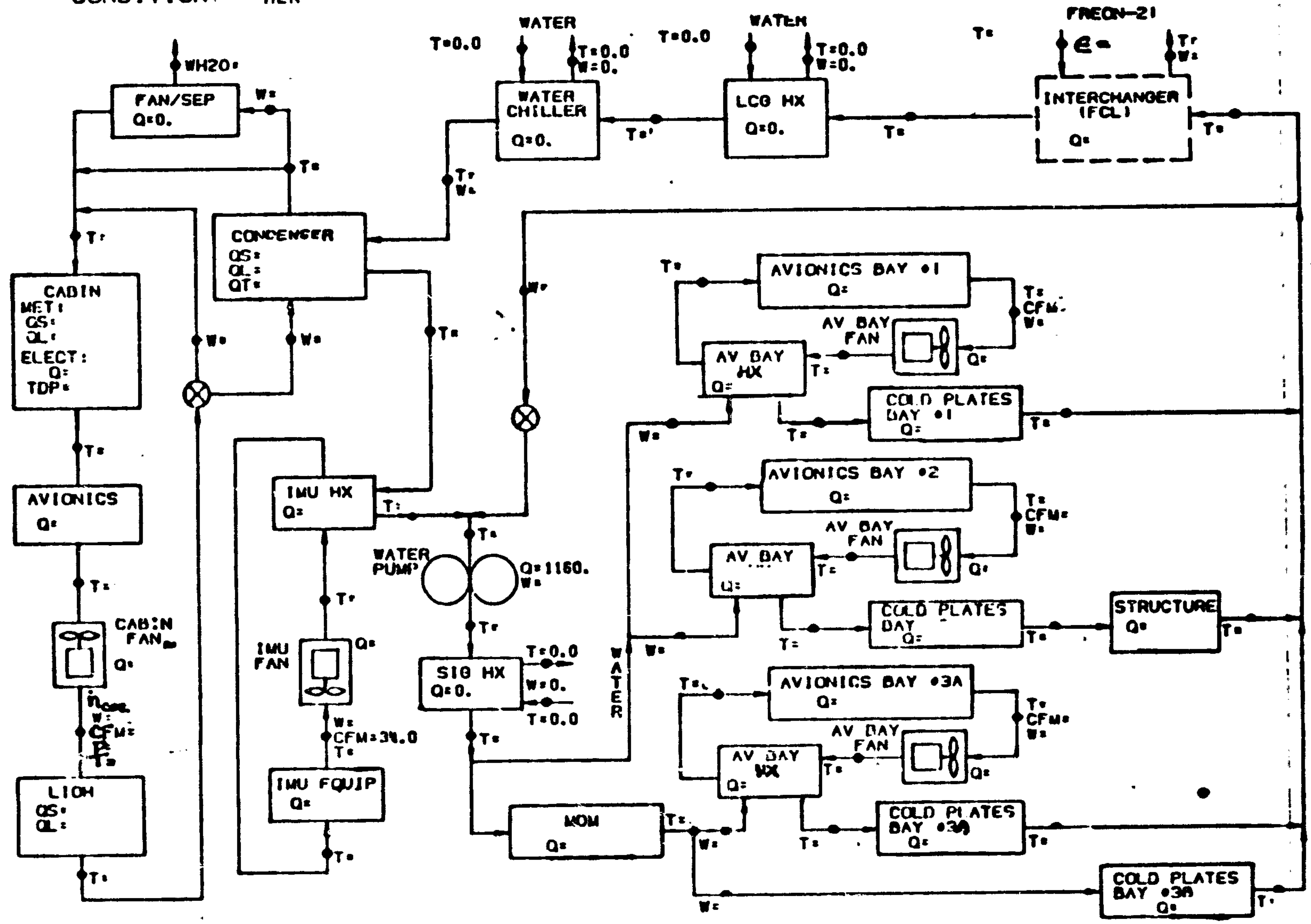
Backup - EVA is the backup mode for accomplishing mission objectives. Mission support equipment is designed for EVA to backup select non-redundant features.

Contingency - EVA is a contingency mode for supporting safe return of the Orbitor to Earth. Tile repair and pyaload bay door closure are examples.

SOURCE: JSC 13000-5 "Flight Assignment Baseline", December, 1980.

## SHUTTLE ARS FLOW CHART

MISSION PHASE–
CONDITION. MEN




UNITS: T,TDP–F°:Q–BTU/HR:W–LB/HR

DATE:

FIGURE 1

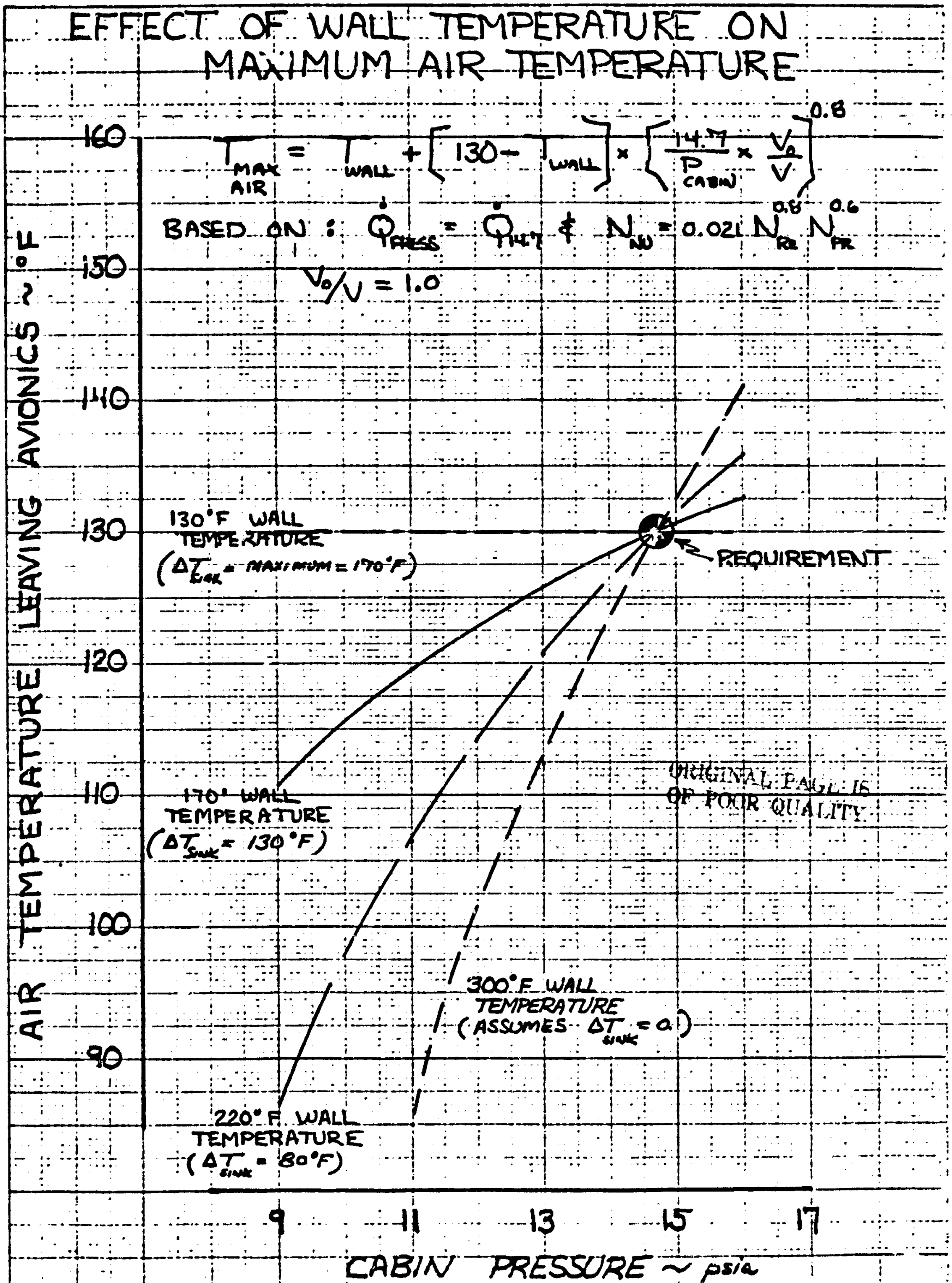


FIGURE 2

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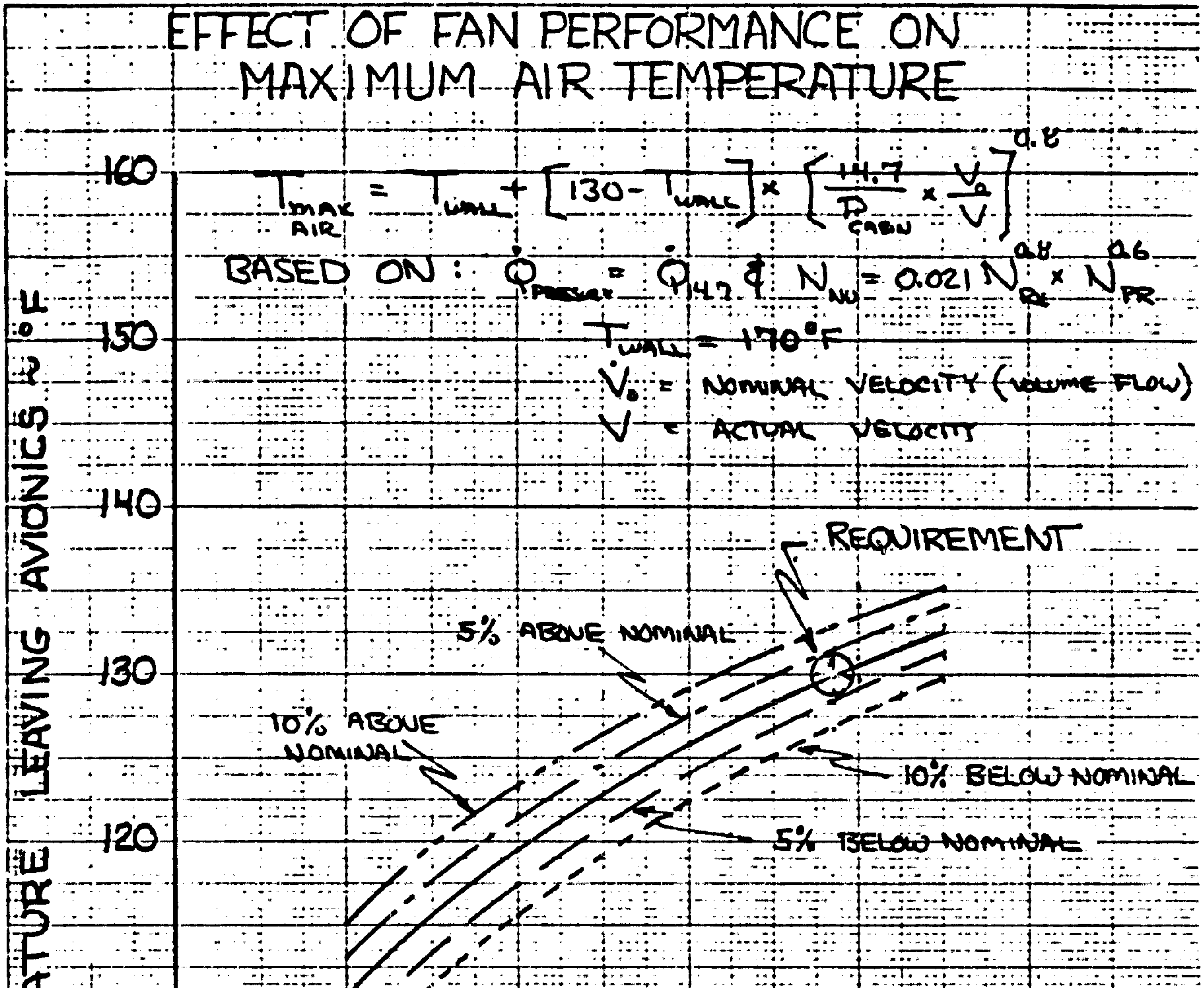
EFFECT OF FAN PERFORMANCE ON
MAXIMUM AIR TEMPERATURE
$T_{MAX\,AIR} = T_{WALL} + \left[130 - T_{WALL}\right] \times \left[\frac{14.7}{P_{CABIN}} \times \frac{V_o}{V}\right]^{0.8}$
BASED ON : $\dot{Q}_{PRESSURE} = \dot{Q}_{14.7}$ & $N_{NU} = 0.021\, N_{RE}^{0.8} \times N_{PR}^{0.6}$
$T_{WALL} = 170°F$
$\dot{V}_o$ = NOMINAL VELOCITY (VOLUME FLOW)
$V$ = ACTUAL VELOCITY
REQUIREMENT
5% ABOVE NOMINAL
10% ABOVE NOMINAL
10% BELOW NOMINAL
5% BELOW NOMINAL
160
150
140
130
120
ATURE LEAVING AVIONICS °F

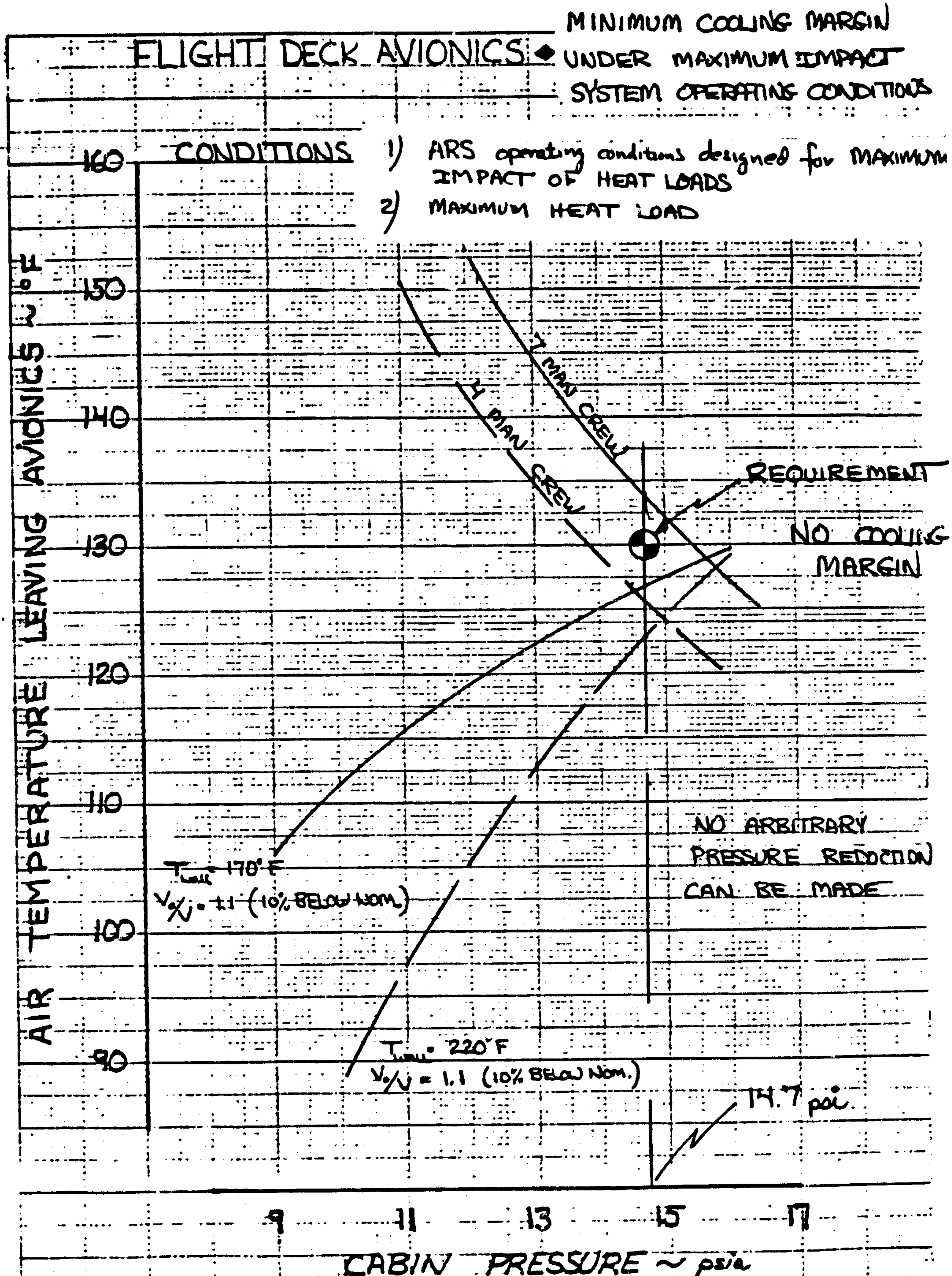
FLIGHT DECK AVIONICS
MINIMUM COOLING MARGIN UNDER MAXIMUM IMPACT SYSTEM OPERATING CONDITIONS
CONDITIONS
1) ARS operating conditions designed for MAXIMUM IMPACT OF HEAT LOADS
2) MAXIMUM HEAT LOAD
AIR TEMPERATURE LEAVING AVIONICS ~ °F
160
150
140
130
120
110
100
90
7 MAN CREW
4 MAN CREW
REQUIREMENT
NO COOLING MARGIN
NO ARBITRARY PRESSURE REDUCTION CAN BE MADE
$T_{wall}$ = 170°F
$V_o/V$ = 1.1 (10% BELOW NOM.)
$T_{wall}$ = 220°F
$V_o/V$ = 1.1 (10% BELOW NOM.)
14.7 psi
9
11
13
15
17
CABIN PRESSURE ~ psia

FIGURE 4

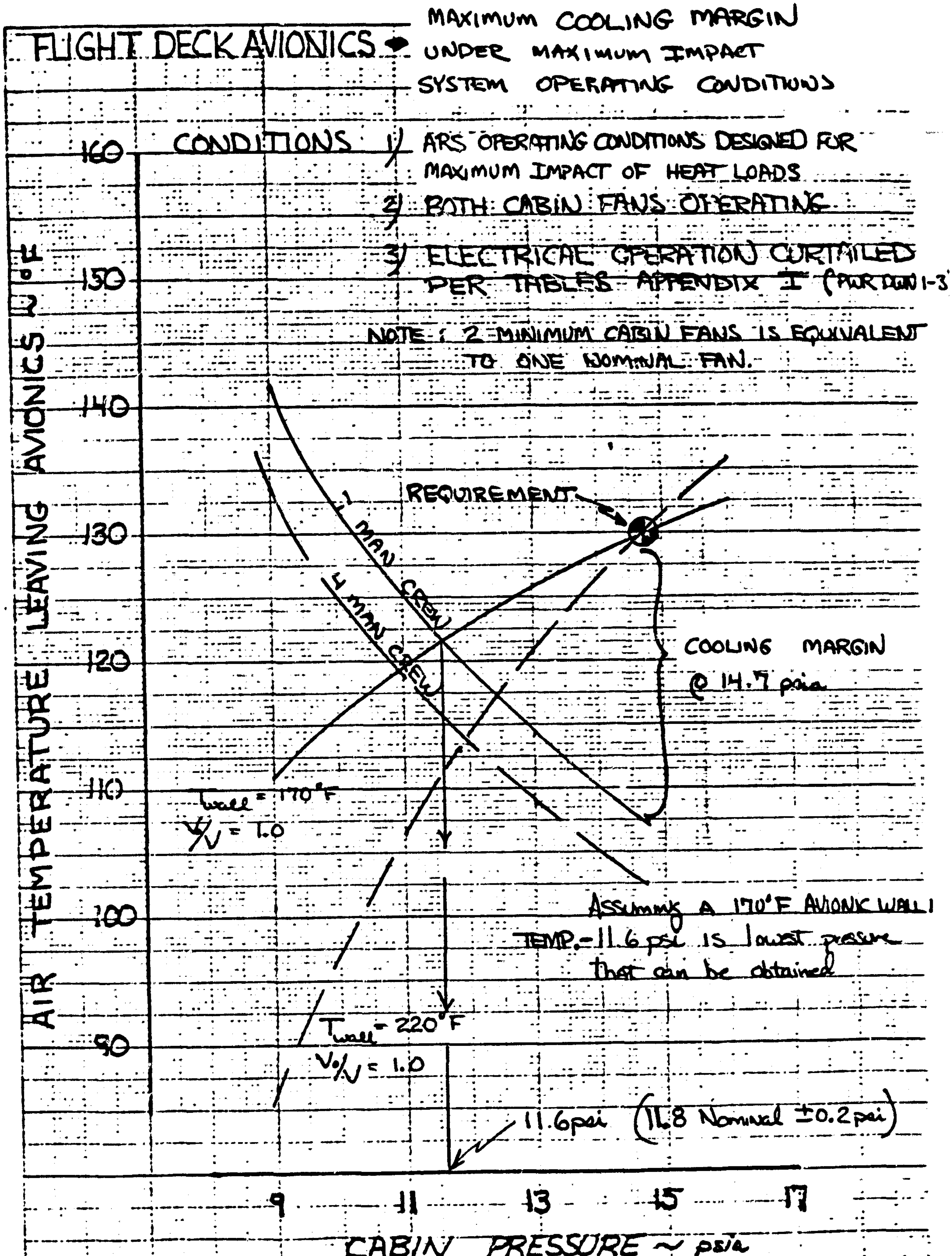

FIGURE 5



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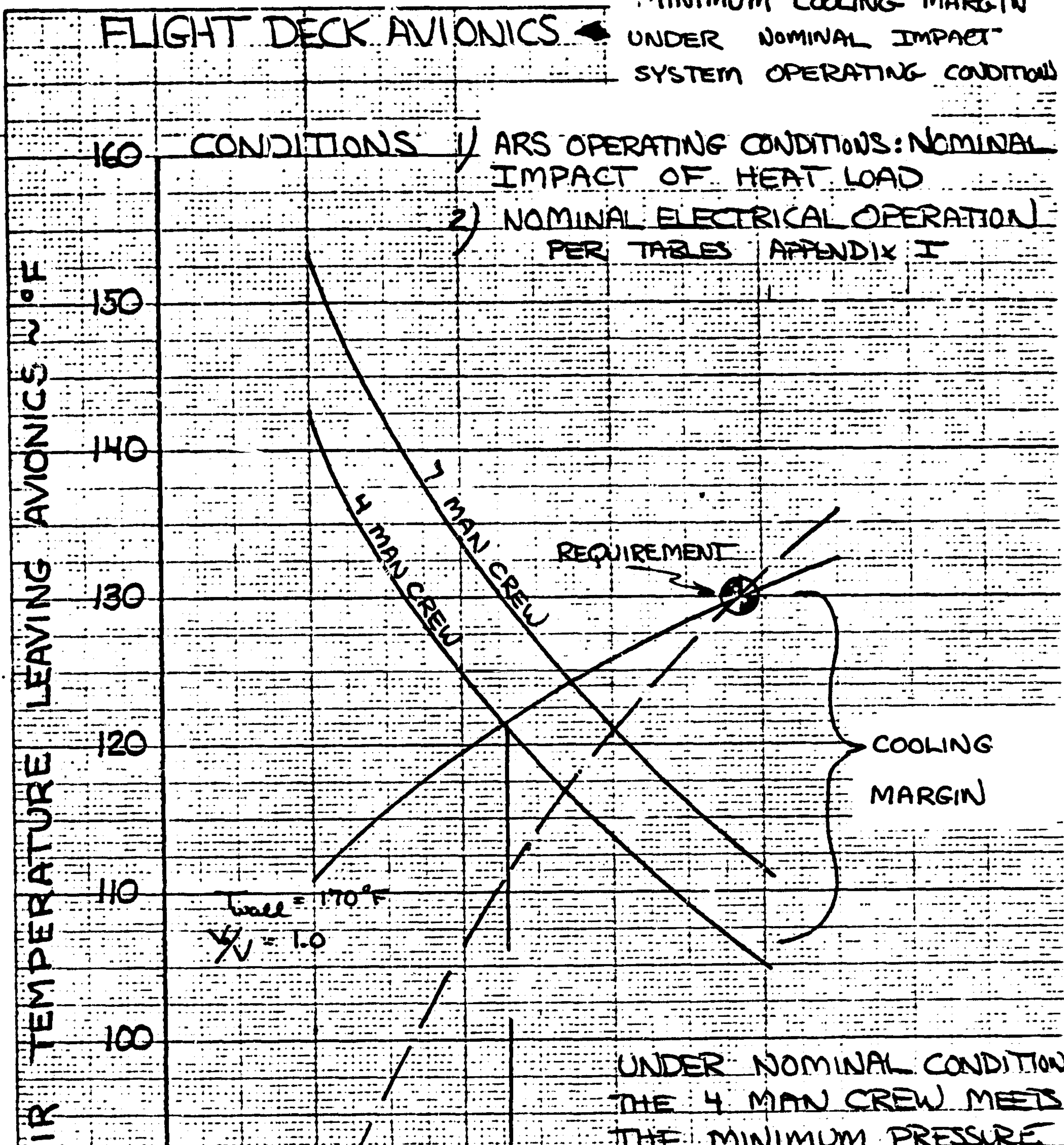

FIGURE 6

C-3



NO. 340-20 DIETZGEN GRAPH PAPER
DIETZGEN CORPORATION

FLIGHT DECK AVIONICS • MAXIMUM COOLING MARGIN UNDER NOMINAL IMPACT SYSTEM OPERATING CONDITIONS

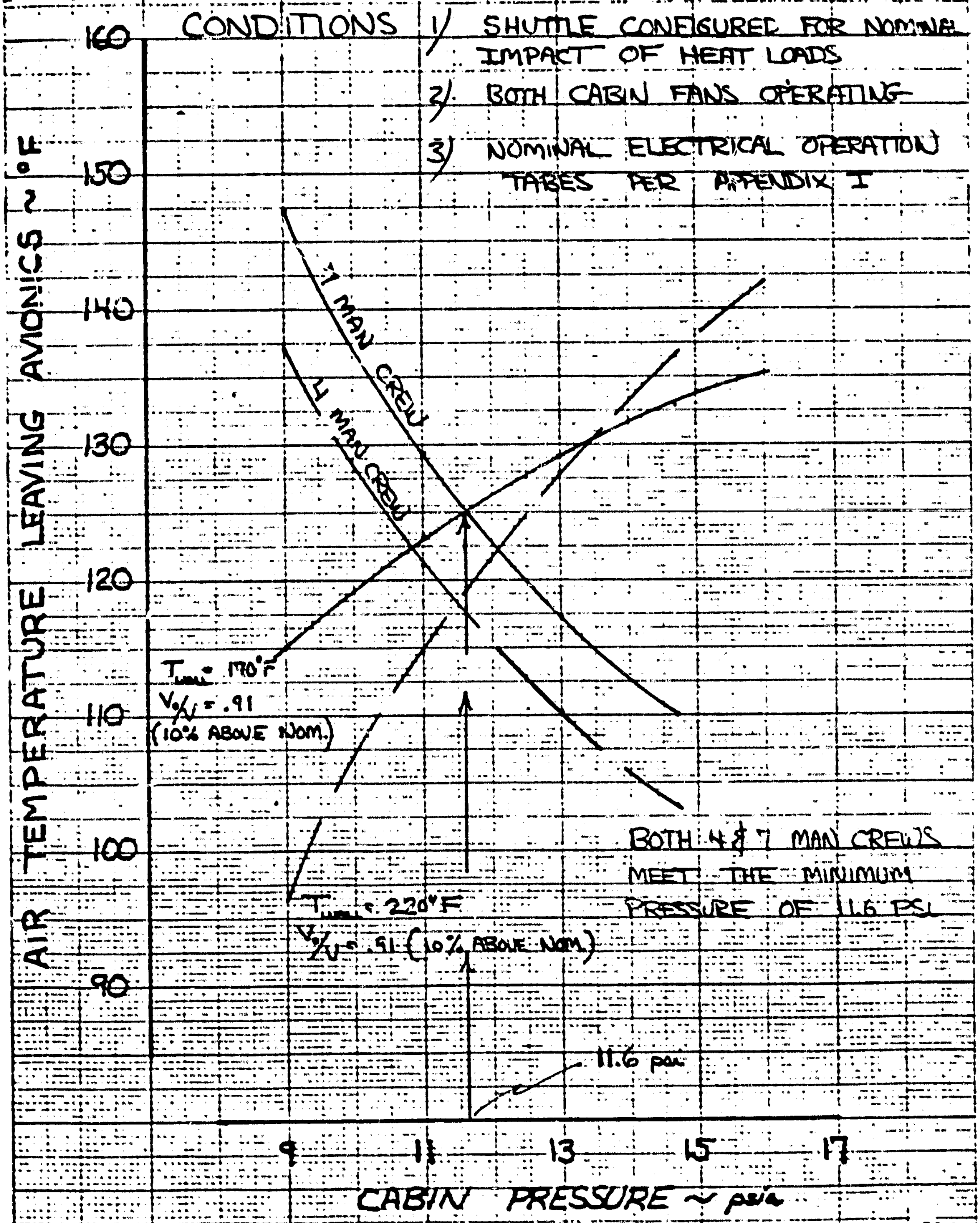


FIGURE 6 A

INERTIAL MEASURING UNITS - ALL THREE UNIT OPERATING (BASELINE OPERATING PROCEDURE)

CASE 1: MINIMUM COOLING MARGIN UNDER MAXIMUM IMPACT CONDITIONS FOR A 7 MAN CREW - FIG. 4

CASE 2: MINIMUM COOLING MARGIN UNDER NOMINAL IMPACT CONDITIONS FOR A 7 MAN CREW - FIG. 6

ALSO MINIMUM COOLING MARGIN UNDER MAXIMUM IMPACT CONDITIONS FOR A 4 MAN CREW - FIG. 4

CASE 3: MAXIMUM COOLING MARGIN UNDER MAXIMUM IMPACT CONDITIONS FOR A 7 MAN CREW - FIG. 5

ALSO MINIMUM COOLING MARGIN UNDER NOMINAL IMPACT CONDITIONS FOR A 4 MAN CREW - FIG. 6

CASE 4: MAXIMUM COOLING MARGIN UNDER MAXIMUM IMPACT CONDITIONS FOR A 4 MAN CREW - FIG. 5

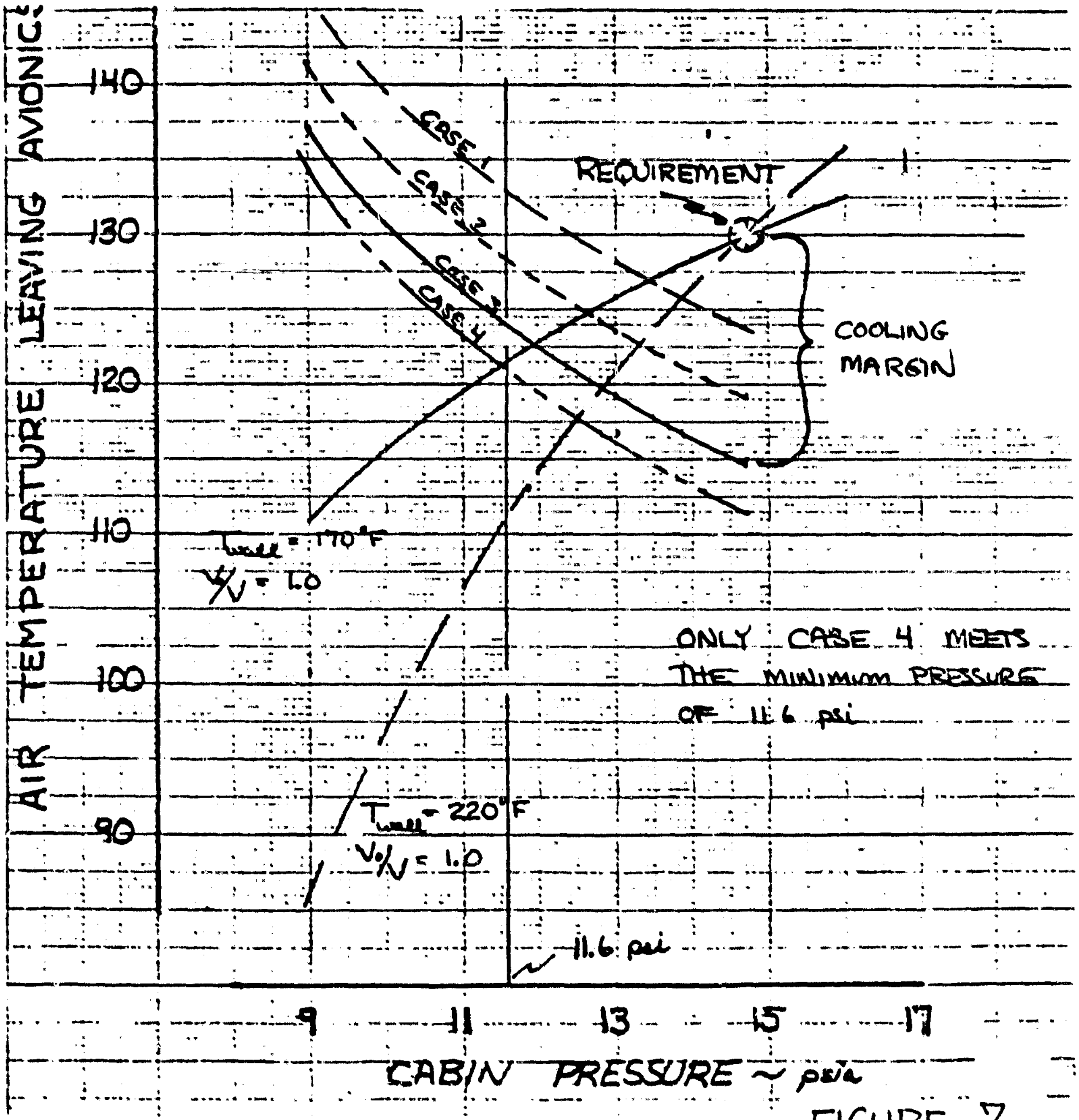


FIGURE 7

INERTIAL MEASURING UNITS • TWO UNITS OPERATING
(PROPOSED OPERATING PROCEDURE)

CASE 1: MINIMUM COOLING MARGIN UNDER MAXIMUM IMPACT CONDITIONS FOR A 7 MAN CREW-FIG. 4

CASE 2: MINIMUM COOLING MARGIN UNDER NOMINAL IMPACT CONDITIONS FOR A 7 MAN CREW-FIG. 6

ALSO MINIMUM COOLING MARGIN UNDER MAXIMUM IPACT CONDITIONS FOR A 4 MAN CREW-FIG. 4

CASE 3: MAXIMUM COOLING MARGIN UNDER MAXIMUM IMPACT CONDITIONS FOR A 7 MAN CREW-FIG. 5

ALSO MINIMUM COOLING MARGIN UNDER NOMINAL IMPACT CONDITIONS FOR A 4 MAN CREW-FIG. 6

CASE 4: MAXIMUM COOLING MARGIN UNDER MAXIMUM IMPACT CONDITIONS FOR A 4 MAN CREW-FIG. 5

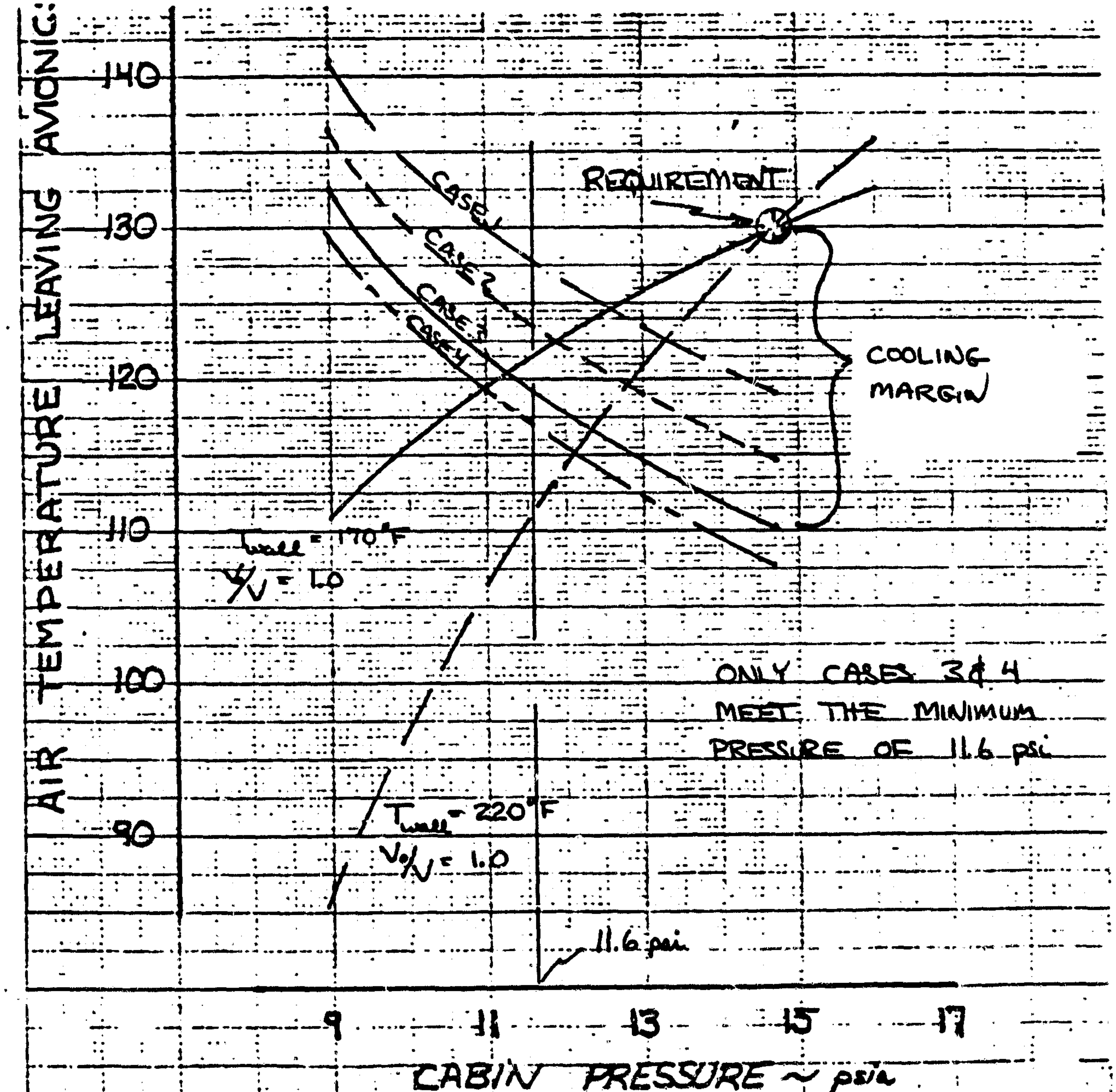


FIGURE 8

## AVIONICS BAY No. 1 ◆ BASELINE RESULTS

CONDITIONS: ALL NON AIRCRAFT/AVIONICS POWERED - ONE FAN

CASE 1: MINIMUM COOLING MARGIN UNDER MAXIMUM IMPACT CONDITIONS FOR A 7 MAN CREW - FIG. 4

CASE 2: MINIMUM COOLING MARGIN UNDER NOMINAL IMPACT CONDITIONS FOR A 7 MAN CREW - FIG. 6

ALSO MINIMUM COOLING MARGIN UNDER MAXIMUM IMPACT CONDITIONS FOR A 4 MAN CREW - FIG. 4

CASE 3: MAXIMUM COOLING MARGIN UNDER MAXIMUM IMPACT CONDITIONS FOR A 7 MAN CREW - FIG. 5

ALSO MINIMUM COOLING MARGIN UNDER NOMINAL IMPACT CONDITIONS FOR A 4 MAN CREW - FIG. 6

CASE 4: MAXIMUM COOLING MARGIN UNDER MAXIMUM IMPACT CONDITIONS FOR A 4 MAN CREW - FIG. 5

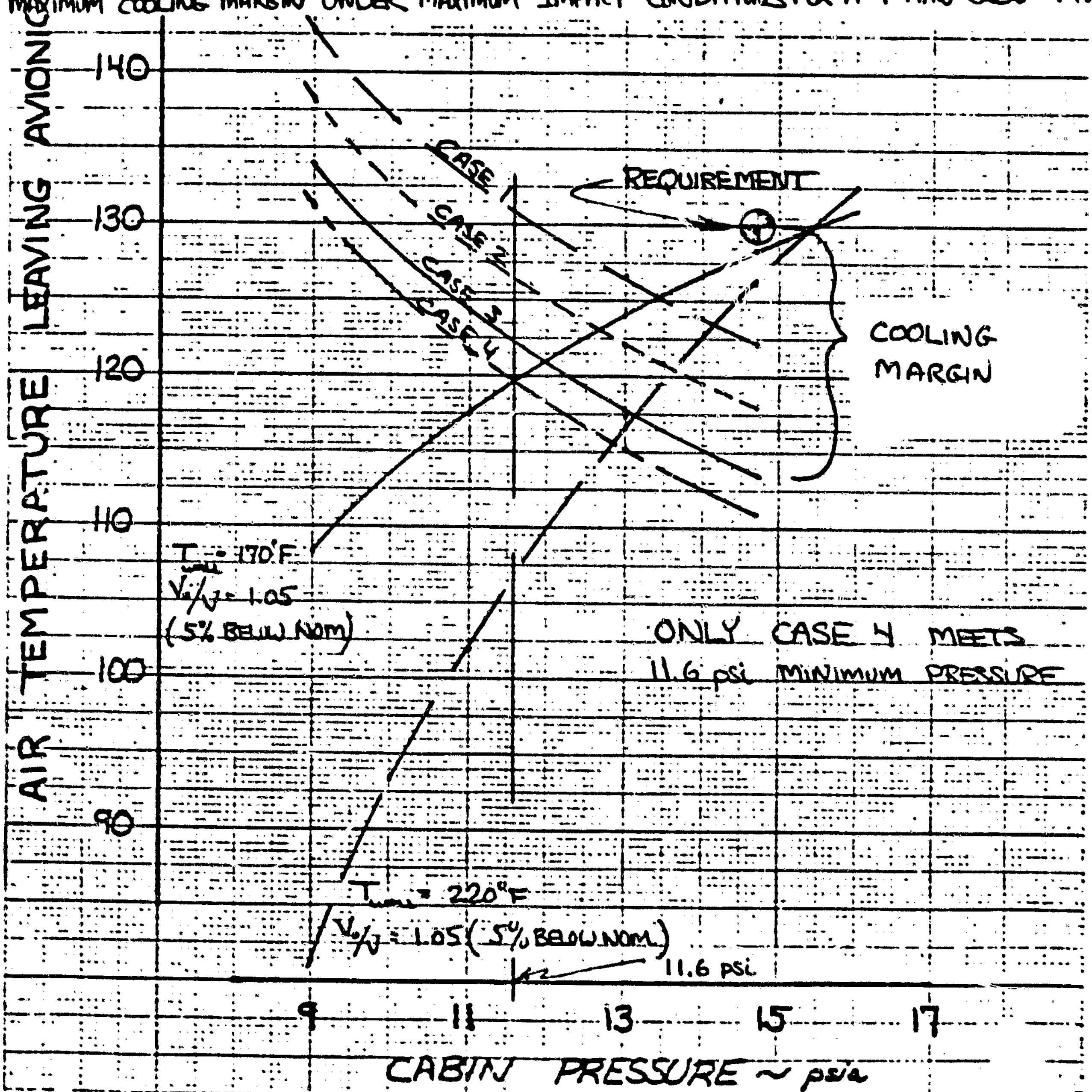


FIGURE 9

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# AVIONICS BAY No. 3 ◆ BASELINE RESULTS

CONDITIONS: ONE FAN: ELECTRICAL OPERATION
PER TABLES APPENDIX I

CASE 1: MINIMUM COOLING MARGIN UNDER MAXIMUM IMPACT CONDITIONS FOR A 7 MAN CREW-FIG. 4

CASE 2: MINIMUM COOLING MARGIN UNDER NOMINAL IMPACT CONDITIONS FOR A 7 MAN CREW-FIG. 6

ALSO MINIMUM COOLING MARGIN UNDER MAXIMUM IMPACT CONDITIONS FOR A 4 MAN CREW-FIG. 4

CASE 3: MAXIMUM COOLING MARGIN UNDER MAXIMUM IMPACT CONDITIONS FOR A 7 MAN CREW-FIG. 5

ALSO MINIMUM COOLING MARGIN UNDER NOMINAL IMPACT CONDITIONS FOR A 4 MAN CREW-FIG. 6

[illegible] MARGIN UNDER MAXIMUM IMPACT CONDITIONS FOR A 4 MAN CREW-FIG. 5

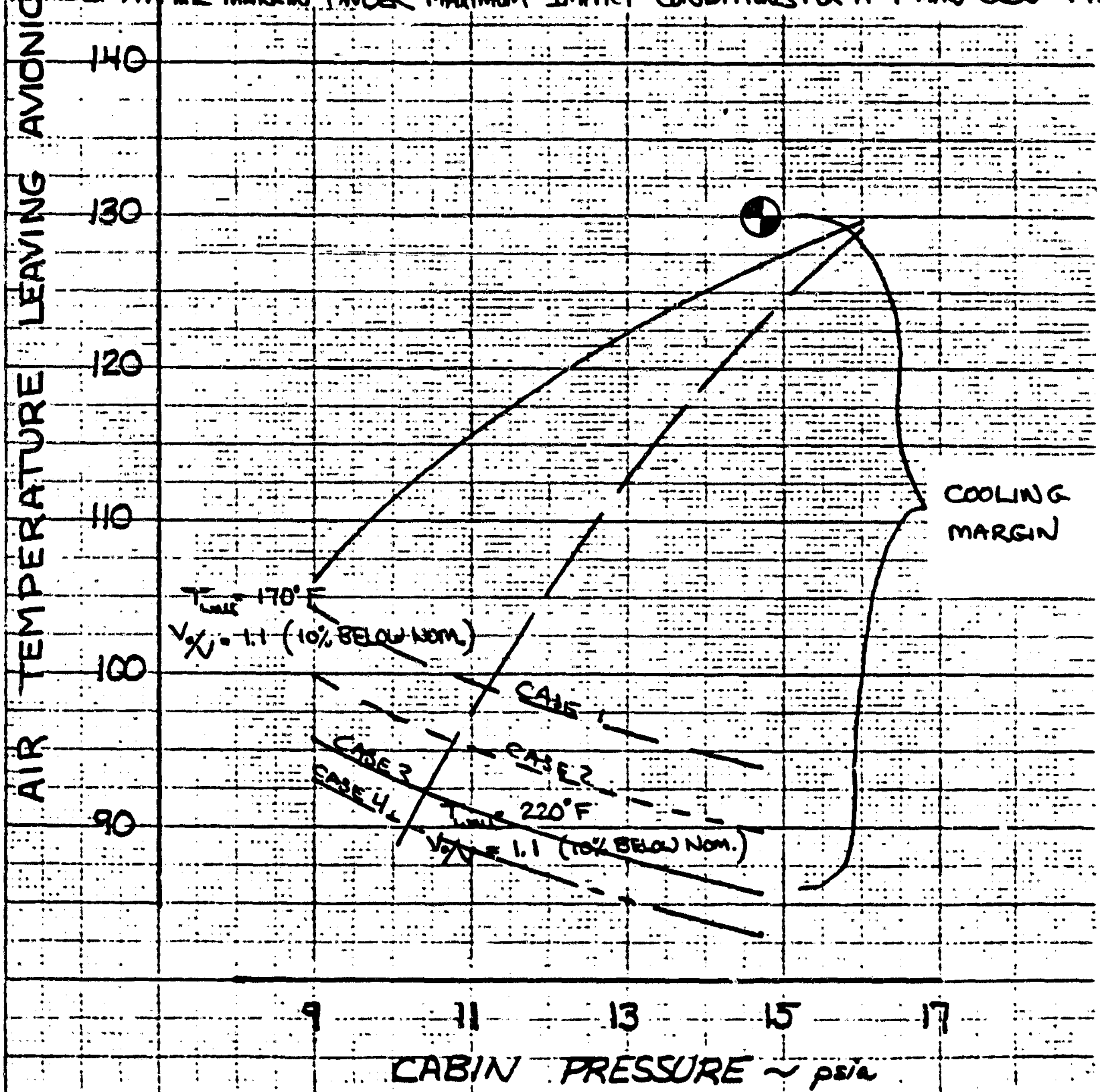


FIGURE 10

# AVIONICS BAY 2 & - BASELINE RESULTS

# AVIONICS BAY 1 - PROPOSED RESULTS

~~CONDITIONS: ALL AIRCRAFT AVIONICS OFF AND ① CPU, ① IOP OFF ONE-FAN~~

CASE 1: MINIMUM COOLING MARGIN UNDER MAXIMUM IMPACT CONDITIONS FOR A 7 MAN CREW - FIG. 4

CASE 2: MINIMUM COOLING MARGIN UNDER NOMINAL IMPACT CONDITIONS FOR A 7 MAN CREW - FIG. 6

ALSO MINIMUM COOLING MARGIN UNDER MAXIMUM IPACT CONDITIONS, FOR A 4 MAN CREW - FIG. 4

CASE 3: MAXIMUM COOLING MARGIN UNDER MAXIMUM IMPACT CONDITIONS FOR A 7 MAN CREW - FIG. 5

ALSO MINIMUM COOLING MARGIN UNDER NOMINAL IMPACT CONDITIONS FOR A 4 MAN CREW - FIG. 6

CASE 4: MAXIMUM COOLING MARGIN UNDER MAXIMUM IMPACT CONDITIONS FOR A 4 MAN CREW - FIG. 5

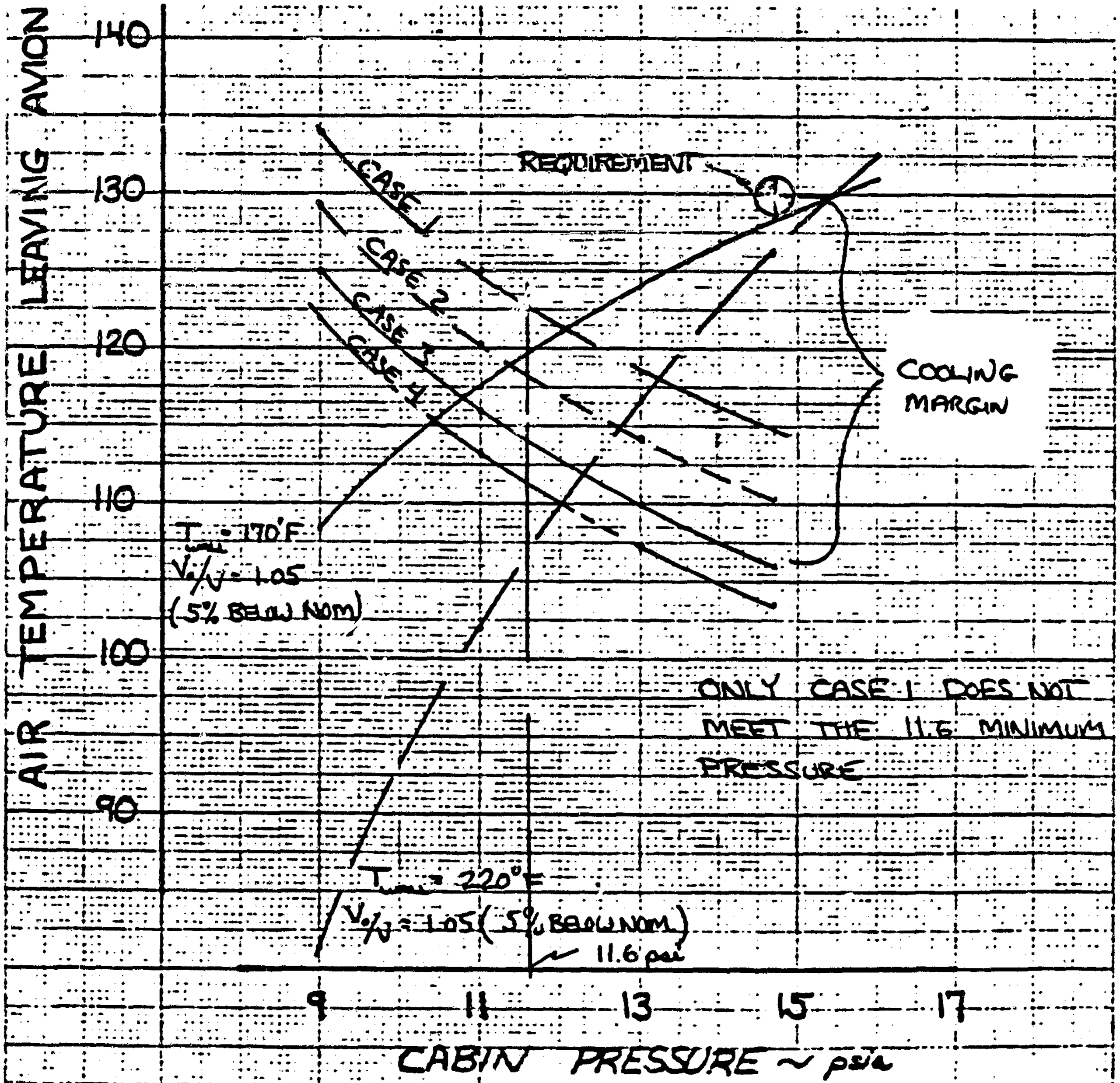


FIGURE 11

# AVIONICS BAY NO. 1 ◆ 2 FAN OPERATION

~~CONDITIONS : 2 FANS~~

ALL NON AIRCRAFT AVIONICS POWERED

CASE 1 : MINIMUM COOLING MARGIN UNDER MAXIMUM IMPACT CONDITIONS FOR A 7 MAN CREW - FIG. 4

CASE 2 : MINIMUM COOLING MARGIN UNDER NOMINAL IMPACT CONDITIONS FOR A 7 MAN CREW - FIG. 6

ALSO MINIMUM COOLING MARGIN UNDER MAXIMUM IPACT CONDITIONS FOR A 4 MAN CREW - FIG. 4

CASE 3 : MAXIMUM COOLING MARGIN UNDER MAXIMUM IMPACT CONDITIONS FOR A 7 MAN CREW - FIG. 5

ALSO MINIMUM COOLING MARGIN UNDER NOMINAL IMPACT CONDITIONS FOR A 4 MAN CREW - FIG. 6

CASE 4: MAXIMUM COOLING MARGIN UNDER MAXIMUM IMPACT CONDITIONS FOR A 4 MAN CREW - FIG. 5

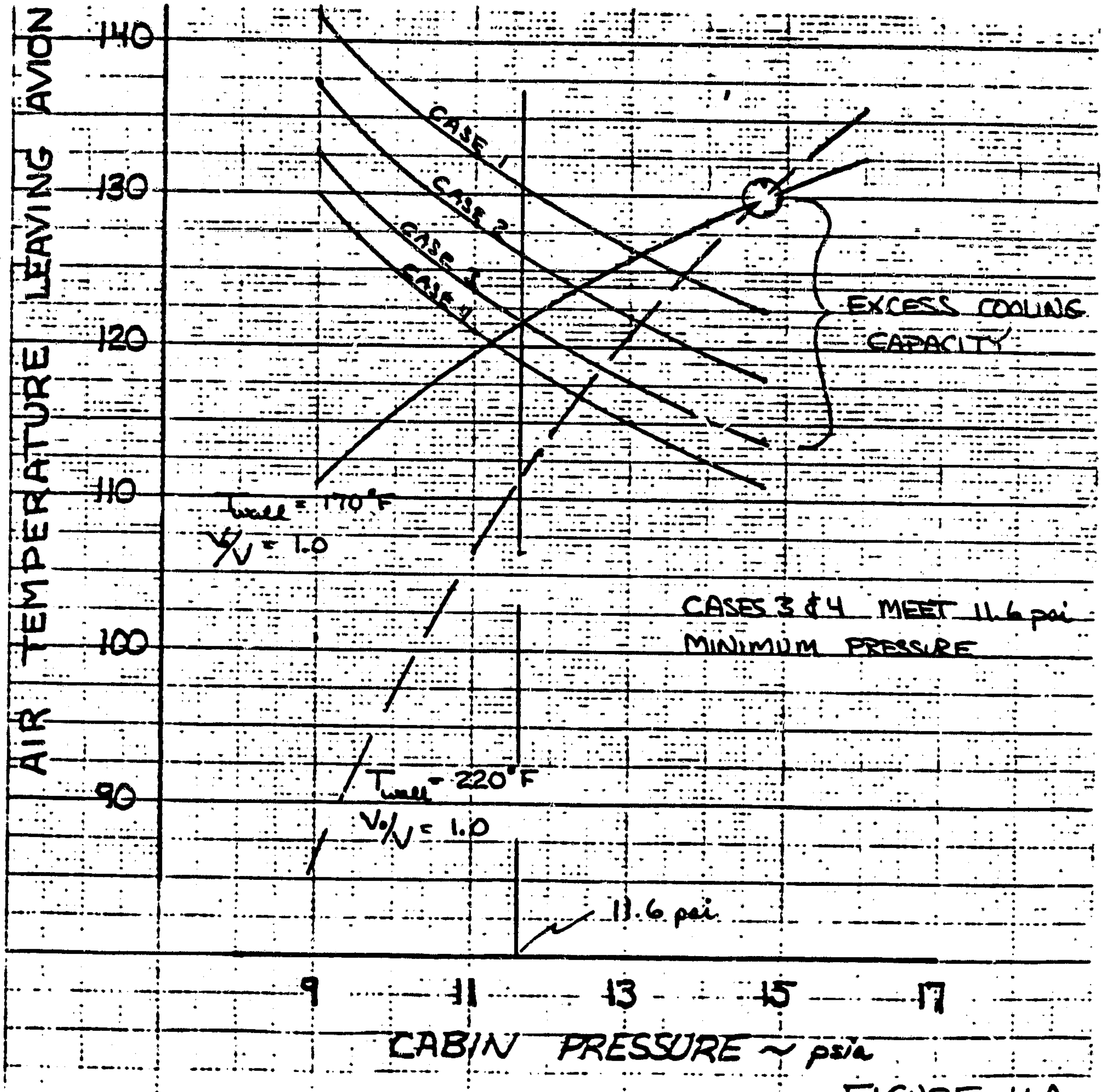


FIGURE 11A

# AVIONICS BAY No. 3 ◆ PROPOSED CASE

CONDITIONS: ALL NON-AIRCRAFT AVIONICS POWERED
ONE FAN MINIMUM PERFORMANCE

CASE 1: MINIMUM COOLING MARGIN UNDER MAXIMUM IMPACT CONDITIONS FOR A 7 MAN CREW - FIG. 4

CASE 2: MINIMUM COOLING MARGIN UNDER NOMINAL IMPACT CONDITIONS FOR A 7 MAN CREW - FIG. 6

ALSO MINIMUM COOLING MARGIN UNDER MAXIMUM IMPACT CONDITIONS FOR A 4 MAN CREW - FIG. 4

CASE 3: MAXIMUM COOLING MARGIN UNDER MAXIMUM IMPACT CONDITIONS FOR A 7 MAN CREW - FIG. 5

ALSO MINIMUM COOLING MARGIN UNDER NOMINAL IMPACT CONDITIONS FOR A 4 MAN CREW - FIG. 6

CASE 4: MAXIMUM COOLING MARGIN UNDER MAXIMUM IMPACT CONDITIONS FOR A 4 MAN CREW - FIG. 5

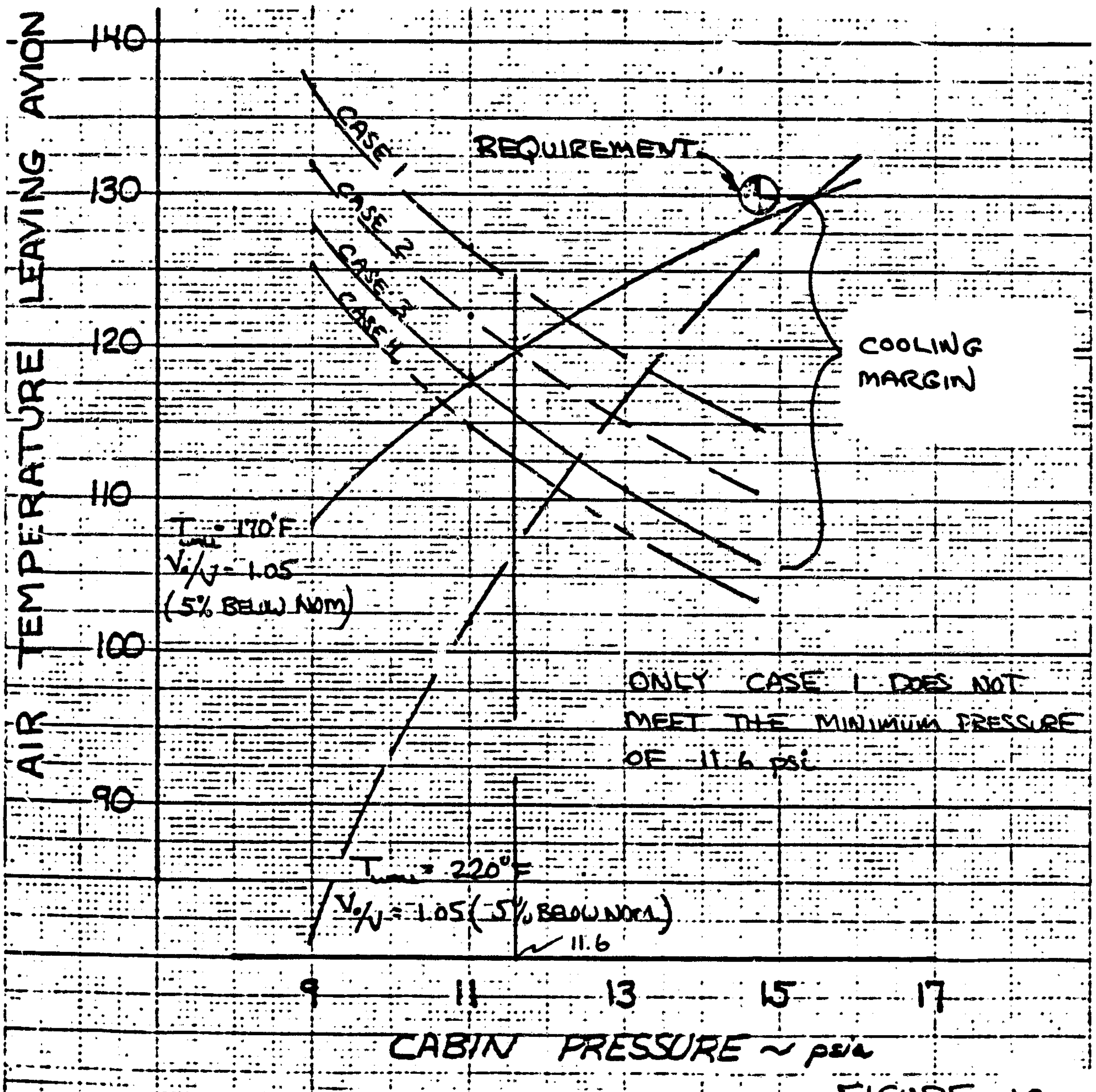


FIGURE 12

APPENDIX I

TABLE I
CABIN
AIR COOLED ELECTRONICS

| ITEM NAME | ACRONYM | HEAT LOAD WATTS | AIR FLOW LB/HR | MISSION PHASE STS 5&6 PROP ORBIT | EVA | STS-1 PWR DN 1-3 |
|---|---|---|---|---|---|---|
| Display Electronic Unit 1 | DEU | 207.3 | 84.2 | | | |
| Display Electronic Unit 2 | DEU | 207.3 | 84.2 | S/D | 2 on | |
| Display Electronic Unit 3 | DEU | 207.3 | 84.2 | 1 | 1 ON STBY | S/D 2 |
| Display Electronic Unit 4 | DEU | 207.3 | 84.2 | OUT OF 4 | 1 OFF | |
| Display Driver Unit 1 | DDU | 120 | 48.8 | | | |
| Display Driver Unit 2 | DDU | 120 | 48.8 | S/D 2 | S/D 2 | S/D 2 |
| Display Driver Unit 3 | DDU | 120 | 48.8 | | | |
| 2 - Mach. Indicator L | AMI | 30 | 12.2 | OFF | OFF | OFF |
| 2 - Mach. Indicator R | AMI | 30 | 12.2 | OFF | OFF | OFF |
| Alt. Vert. Vel. Ind. L | AVVI | 30 | 12.2 | OFF | OFF | OFF |
| Alt. Vert. Vel. Ind. R | AVVI | 30 | 12.2 | OFF | OFF | OFF |
| Display Unit 1 | DU | 90 | 36.6 | | | |
| Display Unit 2 | DU | 90 | 36.6 | S/D 1 | 2 ON | S/D 2 |
| Display Unit 3 | DU | 90 | 36.6 | | 1 OFF | |
| Display Unit 4 | DU | 90 | 36.6 | | 1 STBY | |
| Manip. Intl. Intrf. Unit | MCIU | 200 | 81.2 | ON | ON | N/A |
| Mission Specialist's Station | MSS | 200 | 81.2 | ON | ON | N/A |
| Payload Specialist's Station 1 | PSS | 266.5 | 108.3 | ON | ON | N/A |
| Remote Control Unit | RCU | 20 | 8.1 | ON | ON | N/A |
| Video Interface Unit | VIU | 20 | 8.1 | N/A | N/A | ON |
| Video Switch Unit | VSU | | | | | |
| TV Monitor A | - | 20 | 8.1 | ON | ON | OFF |
| TV Monitor B | - | 20 | 8.1 | ON | ON | OFF |
| Waste Mgmt. System | WMS | INTRMT | 192 | INTRMT | INTRMT | INTRMT |
| Cabin Fan A | | 488 | 1400 | ON | ON | ON |
| Cabin Fan B | | 488 | 1400 | OFF | OFF | OFF |
| Payload Specialist's Station 2 | PSS | 266.5 | 108.3 | ON* | ON* | N/A |
| Payload Specialist's Station 3 | PSS | 266.5 | 108.3 | ON* | ON* | N/A |
| Sensors | - | TBD | 10 | ON | ON | ON |

TABLE I (CON'T)
CABIN
AIR COOLED ELECTRONICS

| ITEM NAME | ACRONYM | HEAT LOAD WATTS | AIR FLOW LB/HR | MISSION PHASE: STS 5&6 ORBIT | MISSION PHASE: PROP EVA | MISSION PHASE: STS-1 PWR DN 1-3 |
|---|---|---|---|---|---|---|
| GFE - Tape Recorder 1 | - | 114 | 120 | ON | ON | ON |
| GFE - Tape Recorder 2 | - | 114 | 120 | ON | ON | OFF |
| Lights | - | 1085 | N/A | ON | ON | OFF |
| Caution & Warning Annum. | C/W Annum | 29 | N/A | ON | ON | ON |
| Speaker/Mike Units | - | 4 | N/A | ON | ON | ON |
| Audio Terminal Units | - | 4 | N/A | ON | ON | ON |
| TV Camera - Flt. Dk. | - | 24 | N/A | ON | ON | ON |
| Computer Status Annunciator | - | 5 | N/A | ON | ON | ON |
| Cabin Temp. Controller A | - | 17 | N/A | ON | ON | ON |
| Cabin Temp. Controller B | - | 17 | N/A | ON | ON | ON |
| Humidity Separator A | - | 28 | N/A | OFF | OFF | OFF |
| Humidity Separator B | - | 28 | N/A | ON | ON | ON |
| Smoke Detector - Flt. Dk. L | - | 6.5 | N/A | ON | ON | ON |
| Smoke Detector - Flt. Dk. R | - | 6.5 | N/A | ON | ON | ON |
| Smoke Detector - LAB | - | 6.5 | N/A | ON | ON | ON |
| Controllers | - | 7 | N/A | ON | ON | ON |
| TV Camera - Middeck | - | 24 | N/A | ON | ON | ON |
| SUBTOTAL FORCE COOLED ELECTRONIC | | | | 2499.4* | 2499.5* | 848.6 |
| SUBTOTAL FREE COOLED ELECTRONICS | | | | 1263.5 | 1263.5 | 178.5 |
| TOTAL (INCLUDING FAN) WATTS | | | | 4251 | 4251 | 1515 |
| TOTAL BTU/HR | | | | 14507 | 14507 | 5171 |

*Payload Specialist Stations 2 and 3 are considered off for 4 man missions
i.e. Subtotal Forced Cooled Electronics = 1966.4

TABLE II
IMU
AIR COOLED ELECTRONICS

| ITEM NAME | ACRONYM | HEAT LOAD WATTS | AIR FLOW LB/HR | MISSION PHASE STS 5&6 PROP ORBIT | EVA | STS-1 PWR DN 1-3 |
|---|---|---|---|---|---|---|
| Inertial Measuring Unit 1 | IMU | 126 | 50 | ON | | ON |
| Inertial Measuring Unit 2 | IMU | 126 | 50 | ON | S/D 1 | ON |
| Inertial Measuring Unit 3 | IMU | 126 | 50 | ON | | ON |
| IMU Fan A | - | 49 | 150 | On | ON | ON |
| IMU Fan B | - | 49 | 150 | OFF | OFF | OFF |
| IMU Fan C | - | 49 | 150 | OFF | OFF | OFF |
| SUBTOTAL FORCE COOLED ELECTRONICS | | | | 378 | 252 | 378 |
| SUBTOTAL FREE COOLED ELECTRONICS | | | | 0 | 0 | 0 |
| TOTAL (INCLUDING FAN) WATTS | | | | 427 | 301 | 427 |
| TOTAL BTU/HR | | | | 1457 | 1027 | 1457 |

TABLE III
AVIONICS BAY #1
AIR COOLED ELECTRONICS

| ITEM NAME | ACRONYM | HEAT LOAD WATTS | AIR FLOW LB/HR | MISSION PHASE STS 5&6 PROP ORBIT | EVA | STS-1 PWR DN 1-3 |
|---|---|---|---|---|---|---|
| Central Processing Unit 1 | CPU/MEM | 336 | 163 | ON | ON | ON |
| Input/Output Processor 1 | IOP/MEM | 394 | 192 | ON | ON | ON |
| Central Processing Unit 4 | CPU/MEM | 336 | 163 | ON | ON | ON |
| Input/Output Processor 4 | IOP/MEM | 394 | 192 | ON | ON | ON |
| Tatical Air Naviation 1 | TACAN | 150 | 73 | OFF | OFF | OFF |
| Microwave Landing System 1 | MLS DCDR | 60 | 30 | OFF | OFF | OFF |
| Air Data Transducer Assy. 1 | ADTA | 64 | 31 | OFF | OFF | OFF |
| Air Data Transducer Assy. 3 | ADTA | 64 | 31 | OFF | OFF | OFF |
| Avionics Bay Fan A | - | 171 | 875 | OFF | OFF | OFF |
| Avionics Bay Fan B | - | 171 | 875 | ON | ON | ON |
| Accelerometer Assy. 1 | AA | 2.5 | N/A | OFF | OFF | OFF |
| Accelerometer Assy. 4 | AA | 2.5 | N/A | OFF | OFF | OFF |
| Microwave Landing System | ILS RF | 22 | N/A | OFF | OFF | OFF |
| Computer Interface Control Unit | CICU | 7 | N/A | ON | ON | ON |
| Inverter D&C 1 | EPDC INV | 2.7 | N/A | ON | ON | ON |
| Power Supply EPDC 1 | EPDC PS | 8 | N/A | ON | ON | ON |
| Smoke Detector A | - | 6.5 | N/A | On | ON | ON |
| Smoke Detector B | - | 6.5 | N/A | ON | ON | ON |
| Skid Control 1 | SKD CNTL | 19.2 | N/A | OFF | OFF | OFF |
| Back-up Flight Control Unit | BFCU | 12 | N/A | ON | ON | ON |
| SUBTOTAL FORCE COOLED ELECTRONICS | | | | 1460 | 1460 | 1460 |
| SUBTOTAL FREE COOLED ELECTRONICS | | | | 42.7 | 42.7 | 42.7 |
| TOTAL (INCLUDING FAN) WATTS | | | | 1673.7 | 1673.7 | 1673.7 |
| TOTAL BTU/HR | | | | 5712 | 5712 | 5712 |

TABLE IV
AVIONICS BAY #2
AIR COOLED ELECTRONICS

| ITEM NAME | ACRONYM | HEAT LOAD WATTS | AIR FLOW LB/HR | MISSION PHASE STS 5&6 ORBIT | MISSION PHASE STS 5&6 PROP EVA | MISSION PHASE STS-1 PWR DN 1-3 |
|---|---|---|---|---|---|---|
| Central Processing Unit 2 | CPU/MEM | 336 | 153 | ON | ON | ON |
| Input/Output Processor 2 | IOP/MEM | 394 | 186 | ON | ON | ON |
| Central Processing Unit 5 | CPU/MEM | 336 | 158 | OFF | OFF | OFF |
| Input/Output Processor 5 | IOP/MEM | 294 | 186 | OFF | OFF | OFF |
| Tactical Air Navigation 2 | TACAN | 150 | 71 | OFF | OFF | OFF |
| Microwave Landing System 2 | MLS DCDR | 60 | 28 | OFF | OFF | OFF |
| Microwave Landing System 3 | MLS DCDR | 60 | 28 | OFF | OFF | OFF |
| Air Data Transducer Assy. 2 | ADTA | 64 | 30 | OFF | OFF | OFF |
| Air Data Transducer Assy. 4 | ADTA | 64 | 30 | OFF | OFF | OFF |
| Avionics Bay Fan A | - | 171 | 875 | ON | ON | ON |
| Avionics Bay Fan B | - | 171 | 875 | OFF | OFF | OFF |
| Accelerometer Assy. 2 | AA | 2.5 | N/A | OFF | OFF | OFF |
| Accelerometer Assy. 3 | AA | 2.5 | N/A | OFF | OFF | OFF |
| Microwave Landing System 2 | MLS RF | 22 | N/A | OFF | OFF | OFF |
| Microwave Landing System 3 | MLS RF | 22 | N/A | OFF | OFF | OFF |
| Inverter D&C 2 | EPDC INV | 2.7 | N/A | ON | ON | ON |
| Power Supply EPDC 2 | EPDC PS | 8 | N/A | On | ON | ON |
| Smoke Detector A | - | 6.5 | N/A | ON | ON | ON |
| SMoke Detector B | - | 6.5 | N/A | ON | ON | ON |
| Skid Control 2 | SKD CNTL | 19.2 | N/A | OFF | OFF | OFF |
| S-Band Switch | S/B SW | 9 | N/A | ON | ON | ON |
| Back-up Flight Control Unit 3 | BFCU | 2 | N/A | ON | ON | ON |
| SUBTOTAL FORCED COOLED ELECTRONICS | | | | 730 | 730 | 730 |
| SUBTOTAL FREE COOLED ELECTRONICS | | | | 36.6 | 36.6 | 36.6 |
| TOTAL (INCLUDING FAN) WATTS | | | | 937.6 | 937.6 | 937.6 |
| TOTAL BTU/HR | | | | 3200 | 3200 | 3200 |

TABLE V
AVIONICS BAY #3A
AIR COOLED ELECTRONICS

| ITEM NAME | ACRONYM | HEAT LOAD WATTS | AIR FLOW LB/HR | MISSION PHASE STS 5&6 ORBIT | MISSION PHASE STS 5&6 PROP EVA | MISSION PHASE STS-1 PWR DN 1-3 |
|---|---|---|---|---|---|---|
| Central Processing Unit 3 | CPU/MEM | 336 | 282 | OFF | OFF | OFF |
| Input/Output Processor 3 | IOP/MEM | 394 | 310 | OFF | OFF | OFF |
| Cuation & Warning | C&W | 35 | 54 | ON | ON | ON |
| Tactical Air Navigation 3 | TACAN | 150 | 117 | OFF | OFF | OFF |
| Avionics Fan A | | 171 | 763 | OFF | OFF | OFF |
| Avionics Fan B | | 171 | 763 | ON | ON | ON |
| S-Band Signal Processor | S/B SP | 6 | N/A | ON | ON | ON |
| S-Band Antenna Switch | S/B ANT SW | 2 | N/A | ON | ON | ON |
| Comm. COP External | COP EXT | 14.7 | N/A | ON | ON | ON |
| Inverter D&C 3 | EPDC INV | 2.7 | N/A | ON | ON | ON |
| Smoke Detector A | - | 6.5 | N/A | ON | ON | ON |
| Smoke Detector B | - | 6.5 | N/A | ON | ON | ON |
| SUBTOTAL FORCE COOLED ELECTRONICS | | | | 35 | 35 | 35 |
| SUBTOTAL FREE COOLED ELECTRONICS | | | | 38.4 | 38.4 | 38.4 |
| TOTAL (INCLDUING FAN) WATTS | | | | 244 | 244 | 244 |
| TOTAL BTU/HR | | | | 834 | 834 | 834 |

TABLE VI
COLDPLATE COOLED EQUIPMENT CONNECTED LOADS

| SYSTEM & PACKAGE | WATTS EACH | BAY 1 WATTS | BAY 2 WATTS | BAY 3A WATTS | BAY 3B WATTS | CABIN WATTS |
|---|---|---|---|---|---|---|
| Flight Control | | | | | | |
| RJDF 1 & 2 | 21.2 | 21.2 | 21.2 | - | - | - |
| Communications | | | | | | |
| CCUA | 40 | 40 | - | | - | - |
| COMSEC 1 & 2 | 25 | - | - | 50 | - | - |
| EVA/ATC | 150 | - | - | 150 | - | - |
| KU/B A 1 & 2 | 123.9 | - | - | 123.9 | 123.9 | - |
| KU/B B 1 & 2 | 47 | - | - | 47 | - | - |
| KU/B SP | 135 | - | - | - | 135 | - |
| N/W SP 1 & 2 | 35 | - | - | 70 | - | - |
| P/L INTG 1 & 2 | 30 | - | 60 | - | - | - |
| P/L SP 1 & 2 | 17 | - | 34 | - | - | - |
| RA 1 & 2 | 23 | 23 | 23 | - | - | - |
| S/B PRE A | 25 | - | - | 25 | - | - |
| S/B PA | 335 | - | - | 335 | - | - |
| S/B XMTR 1 & 2 | 110 | - | - | 220 | - | - |
| S/B XPNDR 1 & 2 | 65 | - | - | 130 | - | - |
| Oper Flight Inst | | | | | | |
| Loop RCDR 1 & 2 | 60 | - | 120 | - | - | - |
| MTU | 31 | - | - | - | 31 | - |
| MSS PCM RCDR | 73 | 73 | - | - | - | - |
| PCM MAST 1 & 2 | 55 | 55 | 55 | - | - | - |
| P/L Data INTL | 50 | 50 | - | - | - | - |
| SC 1, 2 & 3 | - | 15 | 27 | 16 | - | - |
| Elec. Pwr. Dist. & Cont. | | | | | | |
| EVLSS P/S-B/C | 213 | 213 | - | - | - | - |
| GCILU | 30 | - | - | 30 | - | - |
| INV 1 thru 9 | 224 | 672 | 672 | 672 | - | - |
| LCA 1, 2 & 3 | 90 | 90 | 90 | 90 | - | - |
| MCA 1, 2 & 3 | 27/30 | 27 | 30 | 27 | - | - |
| PCA 1, 2 & 3 | 326.2 | 326.2 | 326.2 | 326.2 | - | - |
| Data Proc. | | | | | | |
| MDM FF 1, 2, 3 & 4 | 62.4 | 62.4 | 124.8 | 62.4 | - | - |
| MDM OFI 1, 2, 3 & 4 | 51.9 | 51.9 | 51.9 | 51.9 | - | 51.9 |
| MDM PF 1 & 2 | 59.9 | 59.9 | 59.9 | - | - | - |
| MDM LF | 58.6 | 58.6 | - | - | - | - |
| MM 1 & 2 | 78 | 78 | 78 | - | - | - |
| Water Pump | - | - | - | - | - | 340 |
| TOTAL IN WATTS | | 1916.2 | 1773.1 | 2425.4 | 289.9 | 391.9 |

TOTAL IN BTU/HR = 23198.5

APPENDIX II

# Appendix II

## Reduced Shuttle-Cabin-Pressure Study

from "Handbook of Heat Transfer" by Rohsenow & Hartnett page 7-33

$$N_{NU} = .021\, N_{RE}^{0.8}\, N_{PR}^{0.6} \quad \text{where} \quad N_{NU} = \frac{hD}{K}$$

$$N_{RE} = \frac{\rho V D}{\mu}$$

$$N_{PR} = \frac{\mu C_p}{K}$$

$h$ = coefficient of heat transfer ~ BTU/hr-F

$D$ = hydraulic diameter ~ ft

$K$ = coeff of heat transfer conduction BTU/hr

$\rho$ = density ~ lb/ft³

$V$ = Velocity ~ ft/hr

$\mu$ = viscosity ~ lb/ft-hr

$C_p$ = Specific heat ~ B

Since for a given gas

$$\left.\begin{array}{l} C_p = \text{constant} \\ k = \text{constant} \\ \mu = \text{constant} \end{array}\right\} \text{for constant } T$$

and for a given configuration

$$D = \text{constant}$$

$$\therefore \quad h = \text{constant}\,(\rho V)^{0.8}$$

$$\rho = \frac{m}{V_{ol}} = \frac{P}{RT}$$

&

$$h = \text{constant}\left(\frac{P}{T}\dot{V}\right)^{0.8} \qquad \left\{\begin{array}{l} h_1 = \text{constant}\left[\frac{P_1}{T_1}\dot{V}_1\right]^{0.8} \\ h_2 = \text{constant}\left[\frac{P_2}{T_2}\dot{V}_2\right]^{0.8} \end{array}\right.$$

$$T_1 = T_2$$

$$\frac{h_1}{h_2} = \left[\frac{P_1}{P_2}\frac{\dot{V}_1}{\dot{V}_2}\right]^{0.8}$$

$$h_1 = h_2\left[\frac{P_1}{P_2}\frac{V_1}{V_2}\right]^{0.8} \text{ or } h_P = h_{14.7}\left[\frac{P}{14.7}\times\frac{V_P}{V_{14.7}}\right]^{0.8}$$

$$\dot{Q}_{@P} = \dot{Q}_{14.7\,psia}$$

$$h_p A \overline{\Delta T}_p = h_{14.7} A \overline{\Delta T}_{14.7}$$

where $\Delta T$ = ~~difference~~ log mean difference between avionic wall temperature and air temperature

$$(h_{14.7})\left[\frac{P}{14.7} \times \frac{V_p}{V_{14.7}}\right] A \overline{\Delta T}_p = h_{14.7} A \overline{\Delta T}_{14.7}$$

$$\overline{\Delta T}_p = \left[\frac{14.7}{P} \frac{V_{14.7}}{V_p}\right]^{0.8} \times \overline{\Delta T}_{14.7}$$

~~assume~~ for simplification assume $\overline{\Delta T}_{14.7} = T_{WALL} - T_{AIR_{14.7}}$

$$\overline{\Delta T}_p = T_{WALL} - T_{AIR_p}$$

let $T_{AIR\,14.7} = 130$

$$\left[T_{WALL} - T_{AIR_p}\right] = \left[\frac{14.7}{P} \frac{\dot{V}_{14.7}}{\dot{V}_p}\right]^{0.8} \times \left[T_{WALL} - 130\right]$$

rearranging

$$\boxed{T_{AIR_p} = T_{WALL} + \left[130 - T_{WALL}\right] \times \left[\frac{14.7}{P} \times \frac{\dot{V}_{14.7}}{\dot{V}_p}\right]^{0.8}}$$

# Appendix II

## Maximum Allowable Air Temperature

$$T_{max\ air} = T_{wall} + \left[130 - T_{wall}\right] \times \left(\frac{14.7}{P} \times \frac{V_o}{V}\right)^{0.8}$$

$V_o/V$ 14.7 → STO 0
P → STO 1
$T_{wall}$ → STO 2
130 → STO 3

$V_o/V = 1.0$

| P | 300 | 220 | 170 | 130 |
|---|---|---|---|---|
| | | Twall | | |
| 16 | 141.1 | 135.9 | 132.6 | 130 |
| 14.7 | 130 | 130.0 | 130.0 | |
| 13 | 112.4 | 120.7 | 125.9 | |
| 12 | 85 | 106.5 | 119.6 | |
| 9 | 48 | 86.7 | 110.8 | |
| 3 | | | | |

$V_o/V$ =

$V_o/V = 1.05$ 5% Below Nominal Perf

$V_o/V = 1.1$ 10% Below Nom Perf

$V_o/V = .95$ 5% Above

$V_o/V = .91$ 10% Above

Twall = 170°

| P | $V_o/V$ 1.05 | 1.1 | .95 | .91 |
|---|---|---|---|---|
| 16 | 131. | 129.7 | 134.1 | 135.3 |
| 14.7 | 128.4 | 126.8 | 131.6 | 132.9 |
| 13.0 | 124.1 | 122.4 | 127.6 | 129.1 |
| 11.0 | 117.5 | 115.6 | 121.6 | 123.2 |
| 9.0 | 108.4 | 106.0 | 113.1 | 115.1 |

Twall = 220°

| P | $V_o/V$ 1.05 | 1.1 | .95 | .91 |
|---|---|---|---|---|
| 16 | 132.6 | 129.2 | 139.3 | 142.0 |
| 14.7 | 126.4 | 122.9 | 133.6 | 136.5 |
| 13.0 | 116.7 | 112.8 | 124.7 | 127.9 |
| 11.0 | 102.0 | 97.5 | 111.1 | 114.8 |
| 9.0 | 81.4 | 76.2 | 92.1 | 96.4 |

ECWS-PBE-06

# PREBREATHE ELIMINATION STUDY - EMU IMPACTS

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July 1981

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MEMO HIGHLIGHTS

Title: Prebreathe Elimination Study - EMU Impacts

Object of Memo: Identify impacts to EMU life support subsystem and space suit assembly due to increasing EVA pressure.

Findings and Conclusions:

EVA pressure increases to between 5.25 and 7.50 psia incur the following impacts:

1. Changes to only approximately 15 to 20% of the EMU components would be required. Conversely, approximately 80 to 85% of EMU components would remain unaffected, depending on the EVA pressure selected.

2. Significant impacts to the EMU (those requiring development evaluation) are:

   SOP - $O_2$ capacity requirement rises proportionally with EVA pressure, increasing by 82% at 7.5 psia. Resulting SOP volume increase may drive revision to AAP lower cross bar, in turn affecting the location and stress levels of the Orbiter airlock lower dovetail mounts. SOP volume increase may also affect both MMU "shelf" configuration and ability of suited crew-member to pass through Orbiter interlock hatch. Study is recommended to minimize these impacts.

   Battery - Motor power demand increases with EVA pressure, requiring more battery power. Battery volume increases upwards of 10% at 7.5 psia, but the volume increase is negligible up to approximately 6 psia. PLSS primary structure would require modification to accommodate a larger battery for EVA pressures above approximately 6 psia. Study is recommended to minimize this impact.

   $O_2$ Regulators - Set points of primary and secondary $O_2$ regulators and flow of secondary $O_2$ regulator require change to control revised normal and emergency EVA pressure. Primary changes involve springs and strokes. Stability may be affected and requires evaluation.

   Suit Joints - Torque requirements increase with EVA pressure. Refinement of present joint concepts is expected to minimize the increase up to 6.0 - 6.75 psia EVA pressure. New joint concepts are required for EVA pressures up to 7.5 psia.

   Gloves - Dexterity diminishes rapidly with increasing EVA pressure. New glove technology is expected for EVA pressures above 5.25 - 6.0 psia.

Findings and Conclusions (Continued):

3. Minor impacts to the EMU (those requiring just straightforward design changes) are:

   Strength Margins - External walls of the sublimator, CCC, HUT HTS fiberglass, and PLSS pitot-actuated valve require analytical evaluation. Strengthening in some areas is expected to be required in proportion to the increase in EVA pressure. LTA axial restraints in the waist and hip as well as HUT scye bearings and gimbals require similar analysis. Strengthening is expected to be required in all areas, especially at higher EVA pressures.

   Flow Restrictors - Flow capability of purge valves and other restrictors requires resetting to accommodate higher EVA pressure.

   Relief Valve Settings - Vent loop relief valves require resetting to accommodate higher EVA pressure.

   Other - C & W software and DCM pressure gage require revision to reflect higher EVA pressure.

4. Testing and Handlings - Test rig interface accessories at HS and JSC require only minor modification to support testing at higher EVA pressure. Modifications are typified by gage recalibration and relief valve resetting or installation of new springs. Bench fixtures, ground handling device, and shipping containers may require modification to accommodate a significant increase in SOP volume.

5. Safety - A first aid requirement for explosive decompression from 6 psig or greater during 1 g manned testing is recompression in a hyperbaric facility. Testing at over 6 psia requires that manned testing be conducted only where a hyperbaric facility is available within minutes.

6. New Technology - Two new technology areas have been identified: gloves, to develop improved dexterity at increased EVA pressure; and integrated testing at increased EVA pressure, to insure that all issues are well understood and procedures are verified.

Advantages of Findings:

1. Raising EVA pressure is feasible. Eighty percent or more of EMU items do not require change.

2. Development risks to the LSS are minimal. Most changes do not require development evaluation, and those that do are straightforward engineering problems.

3. Impacts to testing are minimal. Test equipment modifications are minor. Hyperbaric facilities, if required, exist at JSC.

Disadvantages of Findings:

1. Increase in SOP volume may drive changes in MMU and Orbiter airlock wall.

2. Some increase in joint torque is expected. Development is required to minimize the increase.

3. Glove dexterity will be reduced. New technology will be required to offset this loss.

## BACKGROUND

EVA planning for supporting STS flights calls for conducting EVA at 4.0 psia from a 14.7 psia cabin. To preclude "the bends", a painful and potentially dangerous physiological condition resulting from bubble formation when dissolved gasses in body tissues are driven out of solution by exposure to reduced ambient pressure during EVA, STS crewmembers prebreathe pure $O_2$ for 3 to 4 hours to purge body tissues of dissolved $N_2$, the prime constituent of bends bubbles. However, prebreathing has several drawbacks: the crew considers the Portable Oxygen System (POS) to restrict IVA prior to donning the EMU, and denitrogenation can be significantly reduced inadvertently during EMU donning by taking just one or two breaths of air, significantly increasing likelihood of bends, unless specific (and cumbersome) procedures are followed rigorously.

Planning for STS-1 side-steps prebreathing by requiring reduction of cabin pressure to 9 psia for approximately 12 hours prior to EVA, which promotes sufficient washout of dissolved gasses from tissues to minimize likelihood of bends. This is not a permanent solution, because it does not address many Orbiter, payload, operational, and EVA issues relevant to operational STS flights. The objective of the Prebreathe Elimination Study is to define physiologically safe EVA and cabin pressure levels while achieving an acceptable compromise between conflicting Orbiter, payload, operational, and EVA issues. This memo addresses impacts to EMU resulting from raising EVA pressure. Other issues are being addressed elsewhere in the Prebreathe Elimination Study.

## PROBLEM STATEMENT

Prebreathe Elimination Study examines impacts of changing Orbiter cabin pressure and EMU EVA pressure to eliminate pure $O_2$ prebreathe prior to EVA.

Raising EVA pressure increases structural loading of EMU suit and life support elements, increases power requirements, and changes leakage and flow requirements. These impacts must be identified and evaluated for significance in order to define EMU changes required for operation at higher suit pressure.

This memo discusses key EMU life support system and space suit assembly issues as follows:

- Overview of changes required
- Significant LSS impacts
- Minor LSS impacts
- SSA impacts
- Testing and handling.

1. Overview of Changes

The EMU and POS consist of 22 contract end items (CEI's), which are in turn composed of 117 component types and major structural elements. The following tabulation, drawn from Attachment 1, shows that most EMU components and all POS components require no change to support operating the EMU at elevated suit pressure.

| Total Number of EMU and POS Components | Number of components requiring change to operate at higher EVA pressure | | | |
|---|---|---|---|---|
| | PEVA, psia | | | |
| | 5.25 | 6.00 | 6.75 | 7.50 |
| 117 | 19 | 21 | 22 | 25 |
| % of components requiring no change | 84 | 82 | 81 | 79 |

2. Significant Life Support Subsystem Impacts

Attachment 2 lists each POS and EMU LSS CEI and identifies the changes required to support EVA at higher suit pressures. The SOP, battery, and $O_2$ regulators require significant changes, in that extensive redesign is required and development evaluation of the redesign is recommended. These changes also drive additional changes as shown in Table 1.

SOP - The SOP is sized to provide purge flow sufficient to limit inspired $CO_2$ to 15 mm Hg for 30 minutes at a metabolic rate of 1,000 Btu/hr (Reference 2). In addition, it is desirable not to increase the risk of the bends while using the SOP (Reference 3). This requires raising SOP operating pressure in step with rising EVA pressure as shown in Figure 2. This curve retains the same bends risk, i.e., ratio of pre-EVA tissue dissolved gas to emergency EVA pressure of 1.9 as the present SOP, which supports emergency EVA at 3.35 psia after the crewmember is exposed to a 9.0 psia cabin for 12 hours. Figure 1 shows the increase in SOP $O_2$ capacity required to retain present bends risk and $CO_2$ levels as normal EVA pressure rises. The following table, drawn from Figure 1, shows the rapid increase in SOP capacity required to keep pace with increasing EVA pressure.

| PEVA, psia | 5.25 | 6.00 | 6.75 | 7.50 |
|---|---|---|---|---|
| % increase in SOP $O_2$ | 29 | 47 | 64 | 82% |

Enlarging the SOP to accommodate additional $O_2$ will impact the PLSS TMG, the AAP lower crossmember, the airlock wall, the "shelf" on the MMU, and may affect the ability of a suited crewmember to pass through the Orbiter interdeck hatch. These impacts are significant and require development evaluation after implementation. HS recommends that SOP requirements and implementation be reviewed to identify acceptable approaches for minimizing these impacts.

Battery - Increasing EVA pressure causes the fan motor to draw more power, increasing power demand on the battery. The following tabulation, drawn from Attachment 2 and Figure 1, shows the effects on battery power and volume

| PEVA, psia | 5.25 | 6.00 | 6.75 | 7.50 |
|---|---|---|---|---|
| % increase in battery power | 6 | 9 | 13 | 16.4% |
| % increase in battery volume | 0 | 3 | 6 | 10% |

It is expected that up to 6 psia PEVA the battery can be accommodated within the existing PLSS structure. Beyond 6 psia structure will likely require enlargement to accommodate a larger battery. HS recommends that battery requirements and implementation be reviewed to identify acceptable approaches for minimizing impacts to PLSS structure.

$O_2$ Regulators - Resetting the PLSS and SOP $O_2$ regulator requires new springs plus a detailed evaluation of regulator strokes, flow areas and stability which may require additional changes to regulator detail parts. These changes are expected to be straightforward redesign, but require development evaluation. The changes are not expected to require external envelope changes.

3. Minor Life Support Subsystem Impacts

Attachment 2 identifies impacts to CEI's which are straightforward design changes which are not expected to require development evaluation. These include stiffening flat plate areas exposed to increased differential pressure loading, resizing certain orifices, and resetting certain relief valves and regulators. Table 2, drawn from Attachment 2, summarizes the minor LSS impacts.

Raising EVA pressure requires small increases in water and oxygen to cover small additional cooling and leakage requirements. At 7.5 psia an additional 1.4% water and 2.5% oxygen are required. These increases are too small to warrant changing PLSS tankage. Consumables useage rules should be modified slightly to cover these increases.

4. Space Suit Assembly Impacts

Raising EVA pressure has impacts on SSA strength margins, joint performance, and gloves.

Strength Margins - The following areas require strengthening in proportion to the increase in EVA pressure: axial restraints in the LTA waist and brief, and HUT fiberglass, scye gimbals and bearings.

Joint Performance - Table 3 presents the results of an evaluation of present EMU joints tested at EVA pressures up to 7.5 psig. The negative numbers represent increases in joint torque over present 4 psig values. Numbers to the right of the broken line represent joints for which new concepts are required to make practical, working joints. Numbers to the left of broken line represent joints that can be improved by extending present joint construction technology.

Gloves - The EMU glove loses dexterity rapidly with increasing EVA pressure. Technology of the present glove does not appear adequate to support a workable glove above the range of 5.25 - 6.0 psia. Hence a new technology initiative is recommended for developing workable gloves for pressures above 5.25 psia.

5. Testing and Handling

Increasing EVA pressure raises four issues regarding testing and handling: safety, special test equipment, handling fixtures, and integrated testing.

Safety (Reference 4) - If pressure garment integrity is lost suddenly (on the order of one second) at approximately 6 psig or above, lung rupturing may occur which releases air into the pleural cavity. A first aid in managing the escaped air is to repressurize the test subject to several atmospheres in a hyperbaric chamber within 10 to 20 minutes. This procedure helps to control both lung collapse and air bubbles in the bloodstream (air embolism). NASA safety standards require access to a hyperbaric chamber when manned testing is conducted at 6 psig or above. Hyperbaric facilities are available at JSC, where all EMU manned testing at EVA gage pressure has been conducted to date.

Special Test Equipment - Test rigs at Hamilton Standard and NASA JSC are compatible with increased EVA pressure, with just minor modifications. Typical changes include recalibration of vent loop instrumentation, resetting of back pressure controls, and modifying or resetting relief valves. A hardware safety philosophy has dictated inclusion of relief valves in test rig-test item interface accessories to preclude inadvertent isolation of rig-mounted relief valves. These relief valves require resetting or modifications also.

Handling Fixtures - Enlargement of the SOP may require modification of the ground handling device, PLSS/SOP bench fixtures, and CEI 199 shipping container. This assessment would be made at the time of redesign of the SOP.

Integrated Testing - The United States Manned Space Program has conducted all EVA at 4 psia. There is no widespread U.S. experience with higher EVA pressures. A new technology initiative is recommended to conduct an integrated unmanned and manned test program at the selected EVA pressure to gain assurance that issues of higher EVA pressures are well understood and to verify related procedures.

## REFERENCES


1. List of Shuttle EMU and POS Component and CEI Numbers, Philip S. Henzie, Hamilton Standard, February 18, 1981.

2. Memo, Analysis 81-179, "SOP Sizing Criteria," Edward H. Tepper, Hamilton Standard, June 5, 1981.

3. Memo, ECWS-PBE-01, "ECWS Prebreathe Elimination Study - Physiological Aspects," Richard C. Wilde, Hamilton Standard, March 1981.

4. Meeting with D. Horrigan and J. Waligora of NASA JSC SO3, November 3, 1980.

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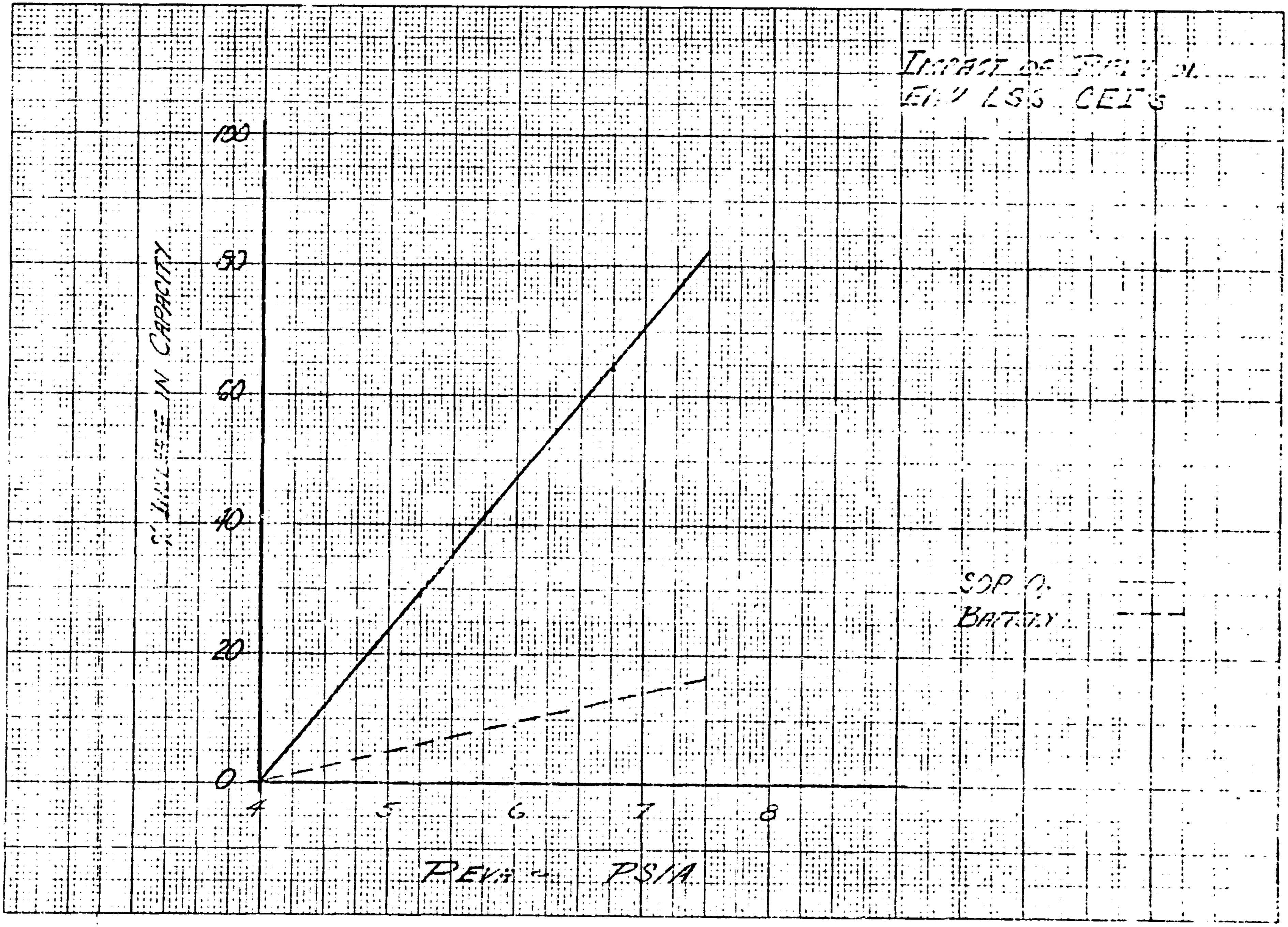

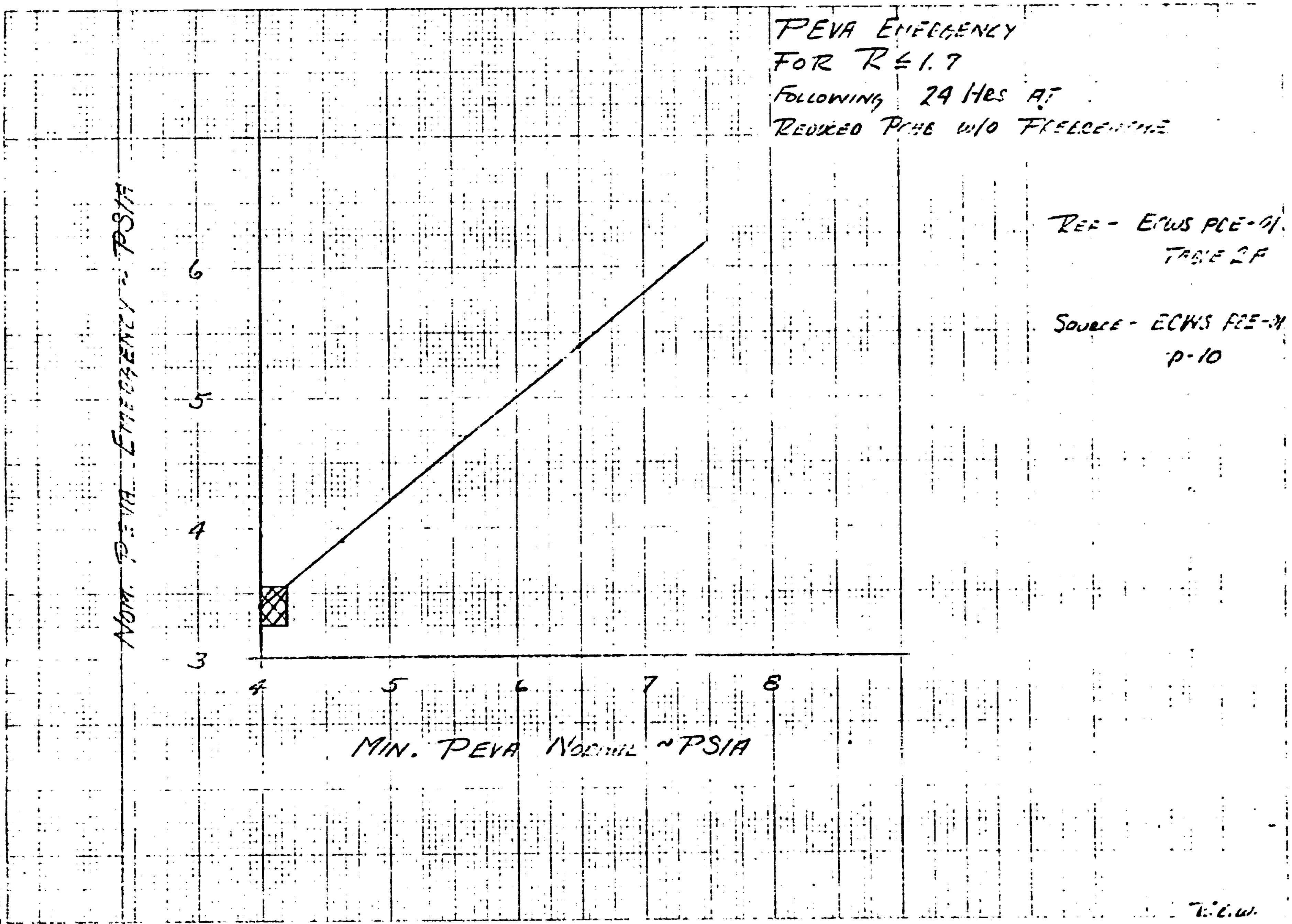


FIGURE 7



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TABLE 1

Significant Impacts to EMU LSS and Interfacing Areas

| Item | Impact |
|---|---|
| SOP | • Increase stored $O_2$ capacity<br>• Enlarge SOP package<br>- May prevent passage through Orbiter interdeck hatch.<br>- Interfere with AAP lower crossbar<br>- Interfere with MMU "shelf" |
| Battery | • Increase capacity<br>• Enlarge battery package<br>- May require modification to PLSS structure. |
| AAP | • Relocate lower crossbar. Expected to require relocation of dovetail mounts in Orbiter airlock wall. |
| PLSS & SOP $O_2$ Regulators | • Modify springs to change set points.<br>• Resize flow orifices as required.<br>• Modify piece parts as required to meet flow requirements<br>• Evaluate stability. |

TABLE 2

Minor Impacts to EMU LSS CEI's

| CEI | Impact |
| --- | --- |
| PLSS | • Strengthen sublimator and pitot-actuated valve. |
| | • Revise 142, 145, and 146 relief valve settings. |
| | • Revise 126 and 141 orifices. |
| | • Revise C & W software limits. |
| DCM | • Revise pressure gage range. |
| | • Revise purge valve flow capacity. |
| SCU | • Revise 418 and 419 regualtor settings. |
| CCC | • Strengthen canister. |

TABLE 3

SSA Impacted Joints

| | PEVA | 5.25 psia | 6.00 | 6.75 | 7.50 |
|---|---|---|---|---|---|
| Shoulder | | -15% | -30% | -50% | -65% |
| Waist | | -20% | -35% | -40% | -60% |
| Brief/Hip | | -10% | -30% | -55% | -70% |
| Elbow | | -10% | -20% | -30% | -65% |
| Knee | | -10% | -20% | -25% | -35% |
| Ankle | | -5% | -10% | -15% | -20% |
| Glove | | | | | |

Extend Existing Concepts ⟵ ⟶ Require New Concepts

ATTACHMENT 1

## Summary of EMU & POS Component Changes

| CEI & Name | | No. of Components (Reference 1) | No. of Changed Components 5.25 | 6.00 | 6.75 | 7.50 psia |
|---|---|---|---|---|---|---|
| 100 | PLSS | 42 w/struct. | 7 | 8 | 9 | 10 |
| 200 | SOP | 4 w/struct. | 2 | 2 | 2 | 2 |
| 300 | DCM* | 16 | 2 | 2 | 2 | 2 |
| 400 | SCU | 10 | 0 | 0 | 0 | 2 |
| 440 | EEH | 1 | 0 | 0 | 0 | 0 |
| 470 | AAP | 1 | 1 | 1 | 1 | 1 |
| 480 | CCC | 1 | 1 | 1 | 1 | 1 |
| 490 | Battery | 1 | 0 | 1 | 1 | 1 |
| 101 | CCA | 1 | 0 | 0 | 0 | 0 |
| 102 | HUT | 2 | 2 | 2 | 2 | 2 |
| 103 | Arms | 1 | 1 | 1 | 1 | 1 |
| 104 | LTA | 1 | 1 | 1 | 1 | 1 |
| 105 | Helmet | 2 | 1 | 1 | 1 | 1 |
| 106 | Gloves | 1 | 1 | 1 | 1 | 1 |
| 107 | LCVG | 1 | 0 | 0 | 0 | 0 |
| 108 | EVVA | 1 | 0 | 0 | 0 | 0 |
| 109 | UCD | 1 | 0 | 0 | 0 | 0 |
| 110 | IDB | 1 | 0 | 0 | 0 | 0 |
| 112 | OPA | 1 | 0 | 0 | 0 | 0 |

| CEI & Name | | No. of Components | No. of Changed Components 11.5 | 12.7 | 13.9 | 15.1 psia |
|---|---|---|---|---|---|---|
| 510 | RBA | 27 | 0 | 0 | 0 | 0 |
| 580 | BH/M | 1 | 0 | 0 | 0 | 0 |
| 590 | RK | 1 | 0 | 0 | 0 | 0 |
| 22 | | 117 | 19 | 21 | 22 | 25 |
| | | % Changed | 16 | 18 | 19 | 21 |
| | | % Unchanged | 84 | 82 | 81 | 79 |

**ATTACHMENT 2**

**Assessment of Increased PEVA on EMU LSS and POS CEI's**

R.C.W.
6-15-81

Sheet 1 of

EMU CEI 100 (No.) PLSS (Name)

| EVA Press (psia) | Structural Modifications for Higher EVA Pressure | Effects of Higher EVA Pressure on Performance | Modifications Required to Retain Present Performance |
|---|---|---|---|
| 5.25 | Sublimator | Revise $H_2O$ tank Relief<br>Gas Trap flow decreases 6%<br>123 Motor Q increases 6%<br>EMU Leakage increases 20%<br>$O_2$ Sensor flow Increase | Revised 113 D Springs<br>Revised 145 & 146 springs<br>Revised 150 C&W Software<br>Revised 113 G Springs<br>Enlarged 141 Orifice<br>Reduced 126 Orifice<br>Increase $O_2$ tank cap 0.E<br>Strengthen 140 Sublimator<br>Increase $H_2O$ tank cap 0.5 |
| 6.00 | Sublimator - 140<br>Potential pkg Size to accommodate larger Battery<br>Pilot Actuated Valve - 125 | Same as above<br>Gas Trap flow decrease 10%<br>123 Motor Q increase 9%<br>EMU leakage increase 46% | Same as above<br>Increase $O_2$ tank cap 1.4<br>Potential Revision to Structure of [illegible]<br>Strengthen 145<br>Increase $H_2O$ tank cap 0.75 |
| 6.75 | Same as above<br>Pkg size increase for larger Battery | Same as above<br>Gas trap flow decrease 13.5%<br>123 Motor Q increase 13%<br>EMU leakage increase 65% | Same as above<br>Increase 111 $O_2$ tank cap 1.<br>Structure Size of THC<br>Increase $H_2O$ tank cap 1.12 |
| 7.50 | Same as above | Same as above<br>Gas Trap flow decrease 17.5%<br>123 Motor Q increase 16.4%<br>EMU leakage increase 83%<br>Raise $H_2O$ tank relief | Same as above<br>Increase 111 $O_2$ tank cap 2.<br>Revised 142 Relief for lower ΔP<br>Increase $H_2O$ tank cap 1. |

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* Note EVA Pressures at which Structural & Performance Discontinuities Occur

4-15-81

Sheet 1 of

EMU CEI 220 (Nº) SOP (NAME)

| EVA $P_{ss}$ (psia) ±0.1 | Structural Modifications for Higher EVA Pressure | Effects of Higher EVA Pressure on Performance | Modifications Required to Retain Present Performance |
|---|---|---|---|
| 5.25 | Package Size Increase | Raise Sec. Reg Set Pt to 4.4 ±.15 psi<br>Emergency Flow Increase 29% | New I 213 Springs & 2nd [illegible]<br>New I 210 Tanks<br>Revise SOP Structure |
| 6.00 | Package Size Increase | Raise Sec Reg Set Pt to 5.0 ±.15 psi<br>Emergency Flow Increase 47% | New I 213 Springs & 2nd<br>New I 210 Tanks<br>Revise SOP Structure |
| 6.75 | Package Size Increase | Raise Sec Reg Set Pt to 5.6 ±.15 psi<br>Emergency Flow Increase 64% | New I 213 Springs & 2nd<br>New I 210 Tanks<br>Revise SOP Structure |
| 7.50 | Package Size Increase | Raise Sec Reg Set Pt to 6.2 ±.15 psi<br>Emergency Flow Increase 82% | New I 213 Springs & 2nd<br>New I 210 Tanks<br>Revise SOP Structure |



* NOTE EVA Pressures at which Structural & Performance Discontinuities Occur

Sheet 1 of 1

EMU CEI 300 (No.) DCM (Name)

| EVA Press ( ) ±0.1 | Structural Modifications for Higher EVA Pressure | Effects of Higher EVA Pressure on Performance | Modifications Required to Retain Present Performance |
|---|---|---|---|
| 5.25 | | Raise vent loop press to 5.25 psi | Increase Range of I311 Gage<br>Decrease I314 purge flow cap |
| 6.00 | | Raise vent loop press to 6.00 psi | Increase Range of I311 Gage<br>Decrease I314 purge flow cap |
| 6.75 | | Raise vent loop press to 6.75 psi | Increase Range of I311 Gage<br>Decrease I314 purge flow cap |
| 7.50 | | Raise vent loop press to 7.5 psi | Increase Range of I311 Gage<br>Decrease I314 purge Flow cap |

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* Note EVA Pressures at which Structural & Performance Discontinuities Occur

[illegible]-81

Sheet 1 of

EMU CEI [illegible] (No.) [illegible] (NAME)

| EVA Press (psia) ±0.1 | Structural Modifications for Higher EVA Pressure | Effects of Higher EVA Pressure on Performance | Modifications Required to Retain Present Performance |
|---|---|---|---|
| 5.25 | None | None | None |
| 6.00 | None | None | None |
| 6.75 | None | None | None |
| 7.50 | None | None | Revised 418 & 410 to accommodate reset $H_2O$ [illegible] pressure |

Sheet ___ of ___

EMU CEI 4?? (No.) — F.E.P. (NAME)

| EVA $P_{SS}$ (psia) ±0.1 | Structural Modifications for Higher EVA Pressure | Effects of Higher EVA Pressure on Performance | Modifications Required to Retain Present Performance |
| --- | --- | --- | --- |
| 5.25 | None | None | None |
| 6.00 | None | None | None |
| 6.75 | None | None | None |
| 7.50 | None | None | None |



* Note: EVA Pressures at which Structural & Performance Discontinuities Occur

EMU CEI [illegible] No.    [illegible] NAME    Sheet _ of _

| EVA Press (psia) ±0.1 | Structural Modifications for Higher EVA Pressure | Effects of Higher EVA Pressure on Performance | Modifications Required to Retain Present Performance |
|---|---|---|---|
| 5.25 | Lower Bottom Bar Restress for increased wt | | |
| 6.00 | Lower Bottom Bar Restress for increased wt | | |
| 6.75 | Lower Bottom Bar Restress for increased wt | | |
| 7.50 | Lower Bottom Bar Restress for increased wt | | |

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* Note EVA Pressures at which Structural & Performance Discontinuities Occur

EMU CEI ____ ____
N° NAME

Sheet __ of __

| EVA Press (psia) ±0.1 | Structural Modifications for Higher EVA Pressure | Effects of Higher EVA Pressure on Performance | Modifications Required to Retain Present Performance |
|---|---|---|---|
| 5.25 | Redress for higher ΔP | | Stronger Containers |
| 6.00 | Redress for higher ΔP | | Stronger Containers |
| 6.75 | Redress for higher ΔP | | Stronger Containers |
| 7.50 | Redress for higher ΔP | | Stronger Containers |

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[illegible]-81

Sheet 1 of

EMU CEI [illegible] No. [illegible] NAME

| EVA Press (psi) ±0.1 | Structural Modifications for Higher EVA Pressure | Effects of Higher EVA Pressure on Performance | Modifications Required to Retain Present Performance |
|---|---|---|---|
| 5.25 | | Motor current increase 6 % | Battery size increase [illegible] |
| 6.00 | | Motor current increase 9 % | Battery size increase 0-2 |
| 6.75 | | Motor current increase 13 % | Battery size increase 3-[illegible] |
| 7.50 | | Motor current increase 16 % | Battery size increase 7-10 |



* NOTE EVA Pressures at which Structural & Performance Discontinuities Occur

2-6-81

Sheet 1 of

EMU CEI 510 N°  PGA NAME

| Cabin ~~EVA~~ Press (psia) ±0.2 | Structural Modifications for ~~Higher EVA~~ Lower Cabin Pressure | Effects of Higher EVA Pressure on Performance | Modifications Required to Retain Present Performance |
|---|---|---|---|
| 9.3 | None | None | None |
| 11.1 | None | None | None |
| 12.3 | None | None | None |
| 13.5 | None | None | None |



* Note EVA Pressures at which Structural & Performance Discontinuities Occur

EMU CEI ___ No. ___ NAME

| (Cabin) EVA Press (psia) ±0.2 | Structural Modifications for ~~Higher EVA~~ Pressure Lower Cabin | Effects of Higher EVA Pressure on Performance | Modifications Required to Retain Present Performance |
|---|---|---|---|
| 9.3 | None | None | None |
| 11.1 | None | None | None |
| 12.3 | None | None | None |
| 13.5 | None | None | None |



* NOTE EVA Pressures at which Structural & Performance Discontinuities Occur

Sheet 1 of

EMU CEI No. ___ RWIM NAME

| EVA Press (psia) 10.2 | Structural Modifications for ~~Higher EVA~~ Pressure Lower Cabin | Effects of Higher EVA Pressure on Performance | Modifications Required to Retain Present Performance |
|---|---|---|---|
| 9.3 | | Deleted - Not Req'd | |
| 11.1 | | Deleted - Not Req'd | |
| 12.3 | | Deleted - Not Req'd | |
| 13.5 | | Deleted - Not Req'd | |

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* NOTE EVA Pressures at which Structural & Performance Discontinuities Occur

5-3-81

Sheet 1 of 1

EMU CEI 102 — Nº

HUT HTS — NAME

| EVA Press (psia) ± 0.1 | Structural Modifications for Higher EVA Pressure | Effects of Higher EVA Pressure on Performance | Modifications Required to Retain Present Performance |
|---|---|---|---|
| 5.25 | Strengthen Fiberglass Shell<br>Stainless Steel gimbal | | |
| 6.00 | Strengthen Fiberglass Shell<br>Stainless Steel Gimbal | | |
| 6.75 | Strengthen Fiberglass Shell<br>Stainless Steel Gimbal<br>Redesign Scye Bearing | | |
| 7.50 | Strengthen Fiberglass Shell<br>Stainless Steel Gimbal<br>Redesign Scye Bearing | | |

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* Note: EVA Pressures at which Structural & Performance Discontinuities Occur

ATTACHMENT 3

Assessment of Increased PEVA
on EMU SSA CEI's

STRUCTURAL AND PERFORMANCE STUDY
OF THE SHUTTLE SPACESUIT ASSEMBLY
AT ELEVATED PRESSURES

PREPARED BY ILC INDUSTRIES, INC.
FOR HAMILTON STANDARD PRE-BREATH
ELIMINATION STUDY, SUMMER 1981

## SCOPE

This study assesses the impact to the Shuttle Spacesuit Assembly (SSA) of operating at elevated pressures (5.25, 6.0, 6.75, 7.5 psia). The study also projects the design changes for each pressure necessary to bring the structural capacity to a minimum safety factor of 2.0 and to bring performance and life to current levels. Only design changes within the scope of the existing concepts of the SSA are considered. This study projects the anticipated cost to bring the suit up to current structural, performance and life levels.

## INTRODUCTION

The Arms, Lower Torso, and Gloves consist of softgoods restraints both, axial lines and bladder restraint. The joints are flat pattern joints. The Upper Torso is a hard shell and is not addressed here. The hardware usage in the suit is limited to bearings, disconnects, and restraint attachment brackets. The latter are the means by which the restraint lines attach to the bearings and disconnects.

## DISCUSSION

Information for this study was collected by two methods - calculation and test. The structural requirements at each pressure were calculated including manned loading then compared to the current capacities as determined by previous test to determine the resultant safety factor. The results of this comparison are shown in Table 1.

The torque and range of the current suit at the elevated pressures was arrived at through unmanned testing using the Cycle Certification Test Suit.

This was done with the Thermal Micromileoroid Garment (TMG) uninstalled as it was unavailable at the time. The torque measurements at the elevated pressures are shown in graph form in Appendix A. The torque and range at 4.0 psi was done at an earlier time as part of certification testing and was done with the TMG installed. The results of both efforts is shown in Table 2. It should be noted that this suit saw more cycling than the required life due to recertifications and general test support for various items.

## RESULTS

The results of this study are shown in Table 3. The results are listed by CEI at each pressure, in each of four categories:

1. Modifications required to upgrade the suit to current performance and life levels and the respective structural requirements.

2. The cost associated with the changes projected in Category 1 under two headings: Non-recurring and Recurring

3. Effects on performance and life if only structural changes required for each pressure are made.

4. Amount of original performance and life that would be reclaimed by incorporating design changes from Category 1.

The design changes noted in Category 1 are based on maintaining the current concepts of the suit, therefore, the lack of entries in some areas indicates the current design concepts would be deficient in accomplishing the requirements. Even current design concepts are not capable of meeting the current performance and life requirements at some pressures but can come relatively close.

Thus the purpose of the last category - the amount of the original performance and life that would be reclaimed by the design changes contemplated in Category 1. The second category shows the cost projections for those pressures for which design changes are possible. The figures listed are for the whole suit rather than CEI's. The non-recurring costs cover design and development, design verification, and certification testing. The recurring costs cover the cost to maintain and support production. The recurring cost would vary depending on the quantity and frequency of deliveries. The third category addresses torque and life as it was found that the range of the joints does not change with pressure. The life portion of the third category uses the current levels listed in the specifications as a measure of the Cycle Life. These levels are: S/AD maximum cycles, Flight - design limit, and Mission - the cycles corresponding to one flight of the Orbiter.

The decision to project the need for design changes at a given pressure in Category 1 is the result of reviewing the safety factors and torque levels and considering the question of cycle life. Therefore, design changes are called for at a lower pressure than any one factor may indicate; this primarily occurs in borderline situations. As a conservative groundrule it was assumed that current torque levels are at or near the limits desired due to suit subject endurance. It is not known whether high torque levels are undesirable or there is some margin before endurance is shortened.

The entries in the last two categories are judgement. Category 3 is a projection based on the torque levels shown in Table 2 keeping in mind the lack of a TMG in place. The entries in Category 4 are engineering projections of the potential of the concepts currently used in the suit.

## CONCLUSIONS

Generally speaking the Shuttle Spacesuit would not perform well above 6.0 psia unless different design concepts were used. The driver of this conclusion is the performance and life. The suit could be strengthened to meet the higher loads of each pressure but the Cycle Life and Torques will diminish the suit's usefulness significantly.

## TABLE 1

### SSA
### SAFETY FACTOR OF CURRENT RESTRAINT LINE DESIGN AT VARIOUS PRESSURES

| RESTRAINT LINE | | 4.0 psi | 5.25 | 6.0 | 6.75 | 7.5 |
|---|---|---|---|---|---|---|
| Glove | | 3.47 | 3.39 | 3.35 | 3.29 | 3.25 |
| Upper Arm | | 4.16 | 3.89 | 3.75 | 3.62 | 3.48 |
| Lower Arm | | 4.66 | 4.48 | 4.36 | 4.27 | 4.18 |
| Waist | | 2.31 | 1.96 | 1.79 | 1.66 | 1.54 |
| Brief | Front | 2.00 | 1.69 | 1.52 | 1.42 | 1.27 |
| | Side | 2.19 | 1.96 | 1.83 | 1.72 | 1.62 |
| Thigh | Inside | 2.33 | 2.14 | 2.03 | 1.94 | 1.86 |
| | Outside | 2.48 | 2.26 | 2.14 | 2.03 | 1.93 |
| Lower Leg | Inside | 4.08 | 3.91 | 3.82 | 3.73 | 3.65 |
| | Outside | 4.66 | 4.44 | 4.33 | 4.20 | 4.10 |
| Boot | Inside | 3.18 | 3.08 | 3.01 | 2.95 | 2.89 |
| | Outside | 3.65 | 3.50 | 3.42 | 3.35 | 3.27 |

## TABLE 2

### TORQUE LEVELS AT MOBILITY LIMITS AT VARIOUS PRESSURES

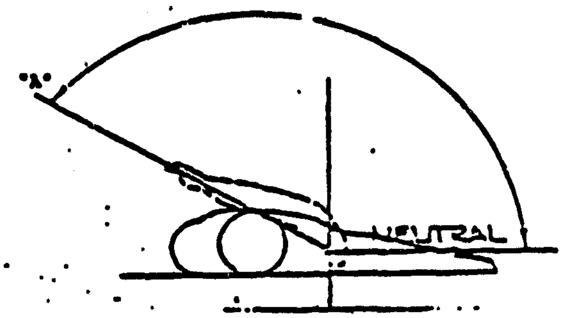
| JOINT | RANGE LIMIT | 4.0 | 5.25 | 6.0 | 6.75 | 7.5 |
|---|---|---|---|---|---|---|
| Shoulder | 140° | 126 | 149 | 151 | 163 | 183 |
| Elbow | 95° | 50 | 66 | 71 | 90 | 104 |
| Waist | 60° | 600 | 456 | 579 | 612 | 739 |
| Hip | 50° | 270 | 225 | 348 | 385 | [illegible] |
| Knee | 100° | 131 | 132 | 156 | 176 | 159 |
| Ankle | 80° | 71 | 43 | 48 | 50 | 58 |

TABLE 3

| | CEI | 5.25 | 6.0 | 6.75 | 7.5 |
|---|---|---|---|---|---|
| Structural Modifications required, maintaining current design & performance | ARM | No change | Redesigned Syce & Arm Bearing - S.S. | ---- | ---- |
| | LTA | Strengthened Brief Restraint | Strengthened restraints repatterned joints. S.S. Waist Bearing | ---- | ---- |
| | GLOVE | No change. | Repattern fingers | ---- | ---- |
| COST | | | | | |
| Recurring | | 381,141 | 525,354 | | |
| Non-Recurring | | 3,250,000 | 3,250,000 | | |
| Effects of structural changes on: | ARM | 15% Increase. | 30% Increase. | 50% Increase in torque. | 65% Increase in torque. |
| Torque | LTA | 15% increase | 30% increase | 40% increase | 60% increase |
| | GLOVE | 10% increase | 30% increase | 50% increase | 65% increase |
| Cycle Life | ARM | Beyond S/AD | 85% of S/AD | Flight | 60% of Flight |
| | WAIST | S/AD | S/AD | Flight | 60% of Flight |
| | GLOVE | 1 Mission | 1 Mission | 70% of Mission | 60% of Mission |
| Reclaimed Mobility & Torque | ARM | 100% | 100% | ---- | ---- |
| | LTA LT | 100% | 80% - 90% | ---- | ---- |
| | Waist | 95% | 80% | ---- | ---- |
| | GLOVE | 95% | 90% | | |

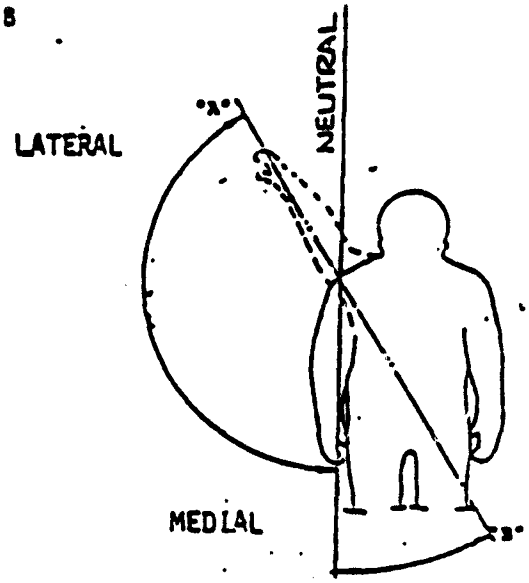
# APPENDIX A

A



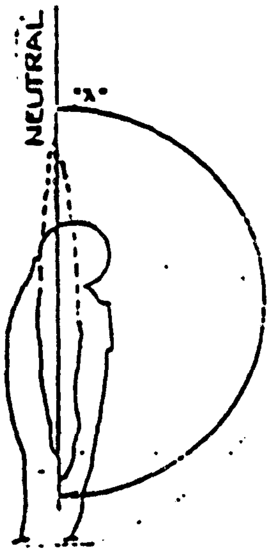

SHOULDER ADDUCTION/ABDUCTION

B



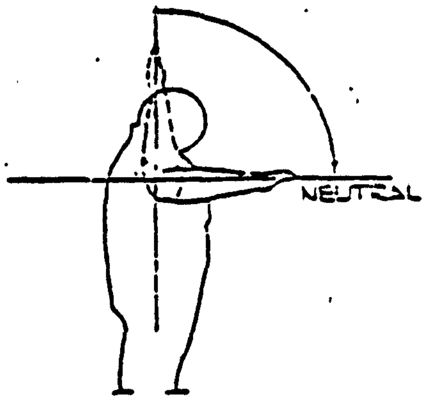

SHOULDER LATERAL/MEDIAL

C




SHOULDER FLEXION/EXTENSION

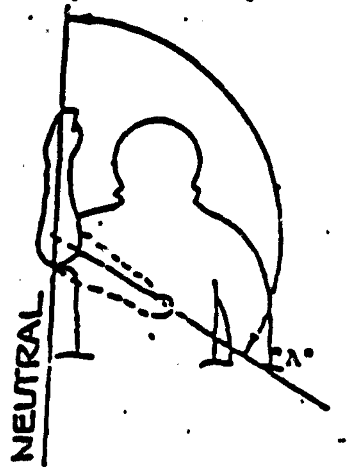
D




SHOULDER ROTATION
(X-Z PLANE)

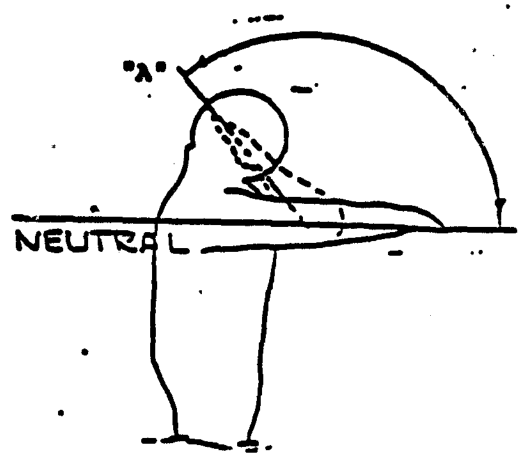
E

SHOULDER ROTATION LATERAL-MEDIAL
(Y-Z PLANE)



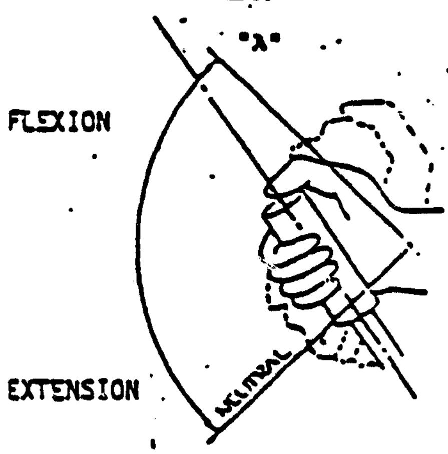

E

ELBOW FLEXION/EXTENSION



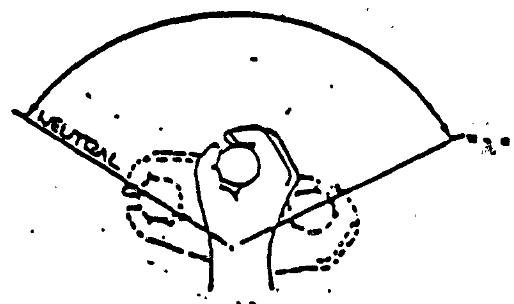

G

WRIST FLEXION/EXTENSION

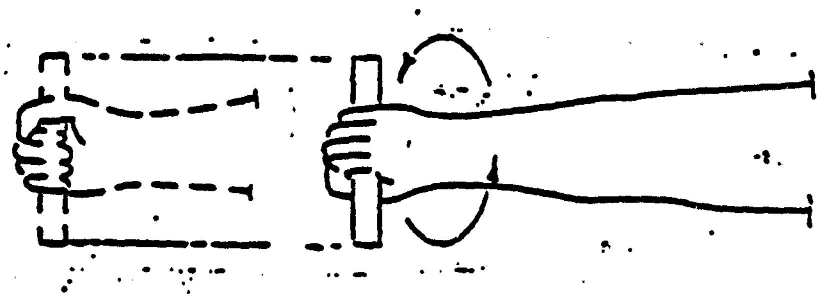



H

WRIST ADDUCTION/ABDUCTION



I



WRIST ROTATION

J

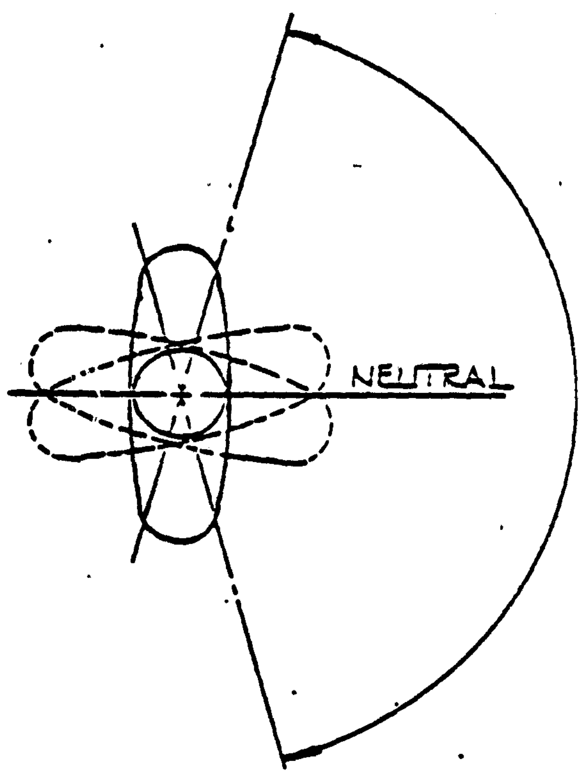



ILLUSTRATION IS FOR
MOBILITY MEASUREMENT
REFERENCE ONLY

WAIST ROTATION



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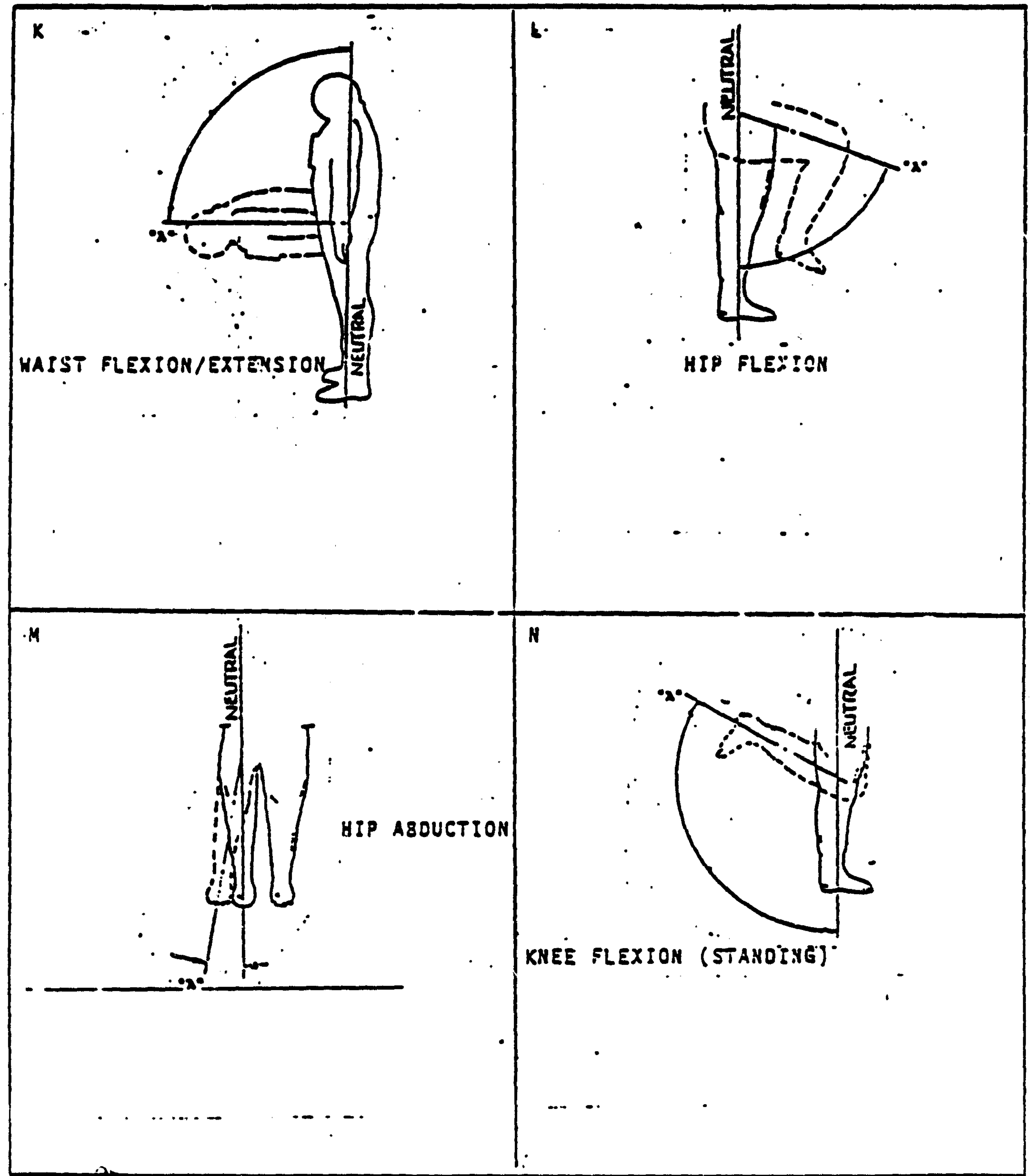
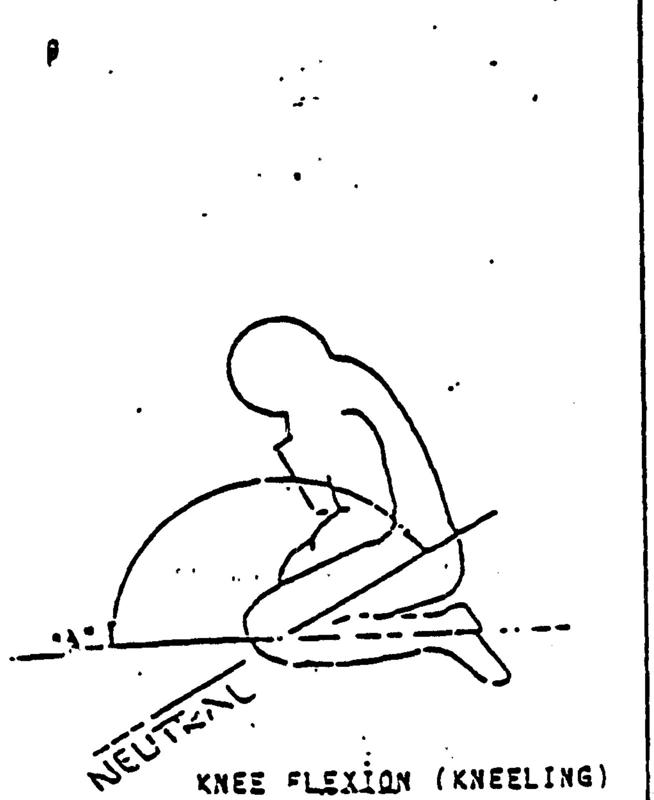
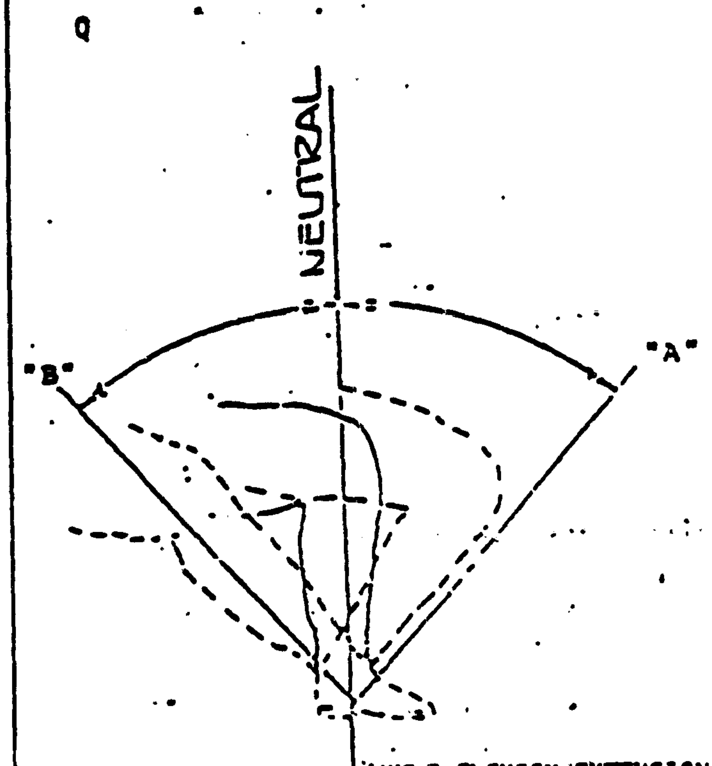
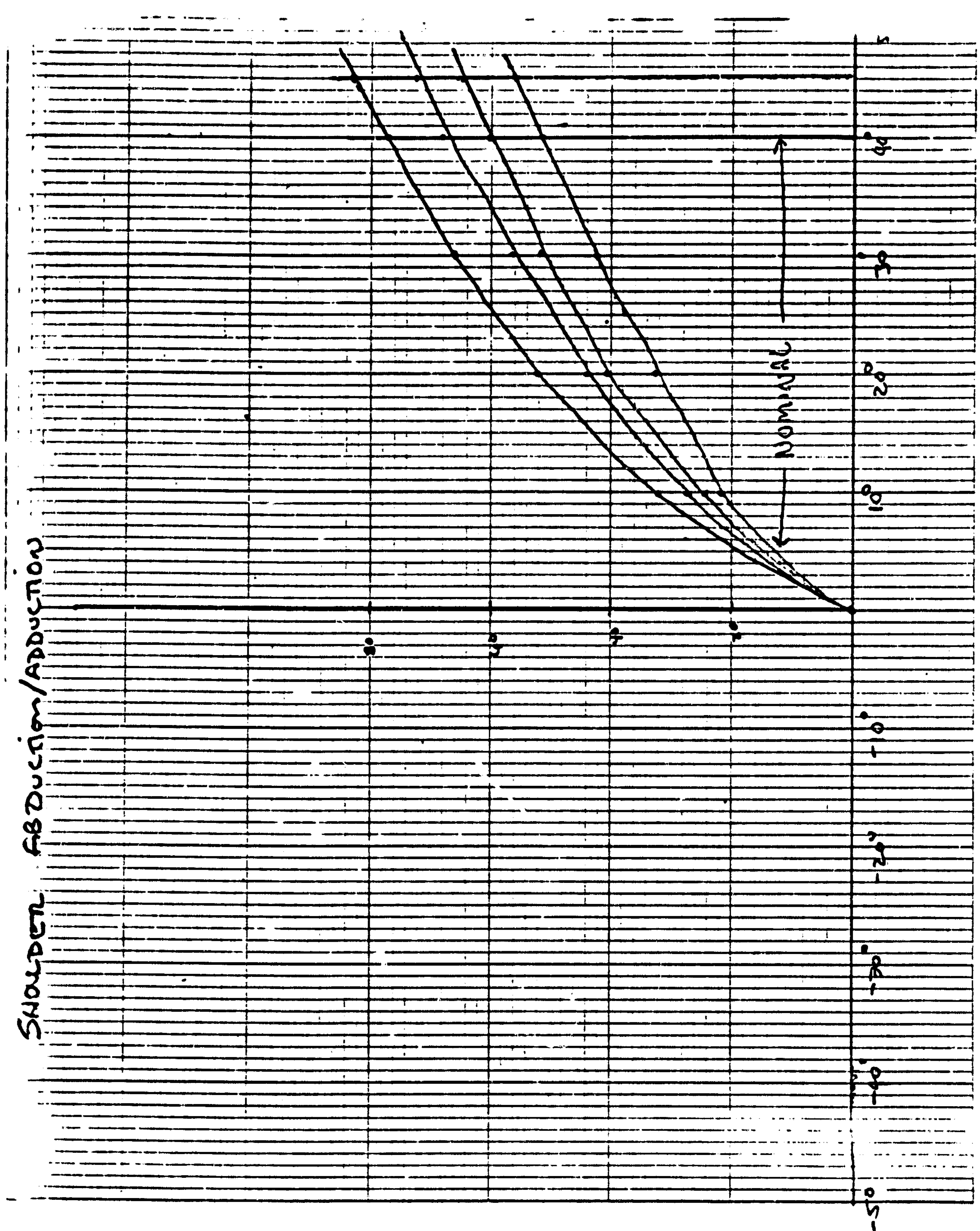

K
NEUTRAL
"A"
WAIST FLEXION/EXTENSION
L
NEUTRAL
"A"
HIP FLEXION
M
NEUTRAL
"A"
HIP ABDUCTION
N
"A"
NEUTRAL
KNEE FLEXION (STANDING)

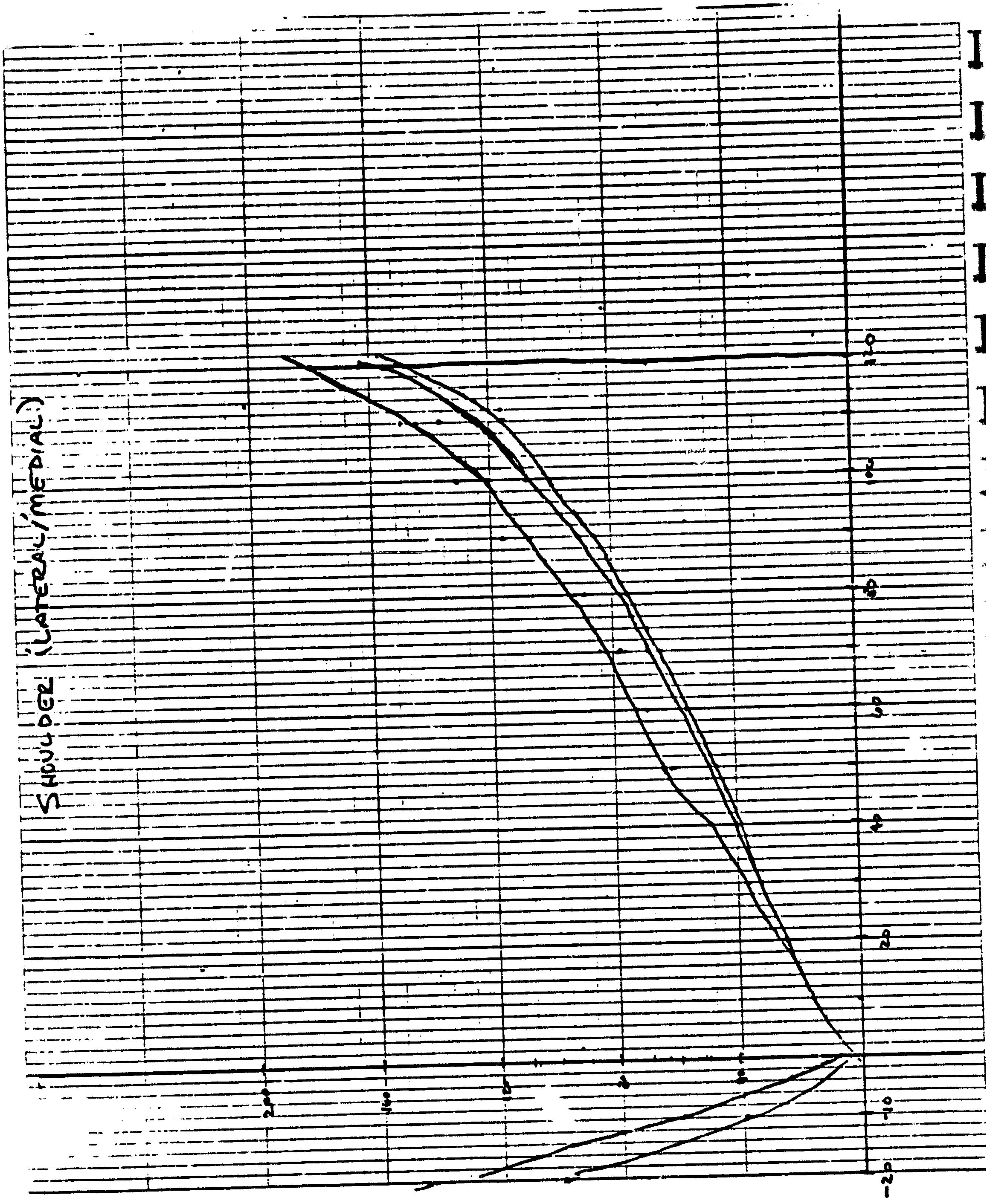



KNEE FLEXION (KNEELING)



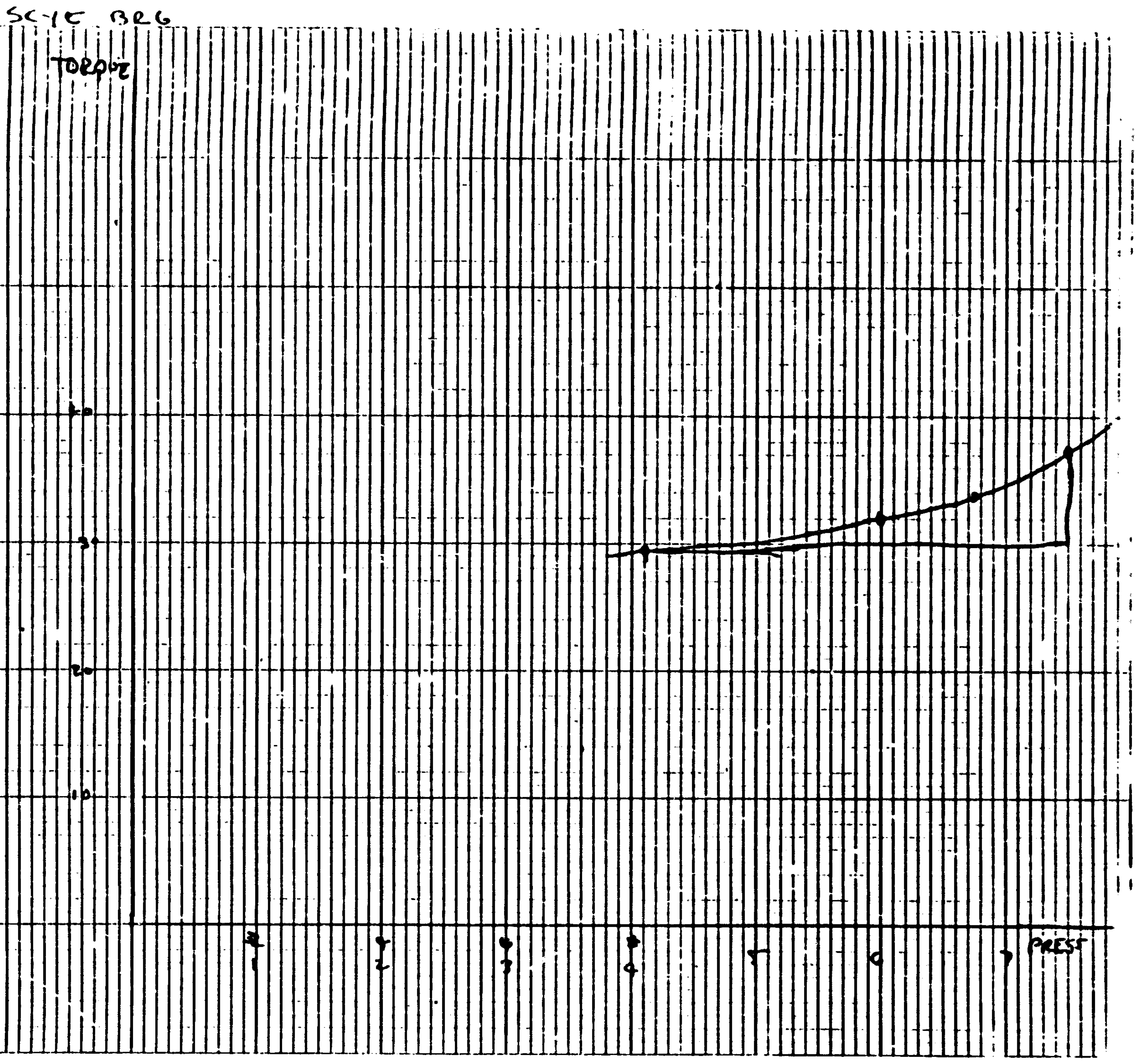

ANKLE FLEXION/EXTENSION


SHOULDER ABDUCTION/ADDUCTION
NOMINAL
50
40
30
20
10
-10
-20
-30
-40
-50
.8
.6
.4
.2

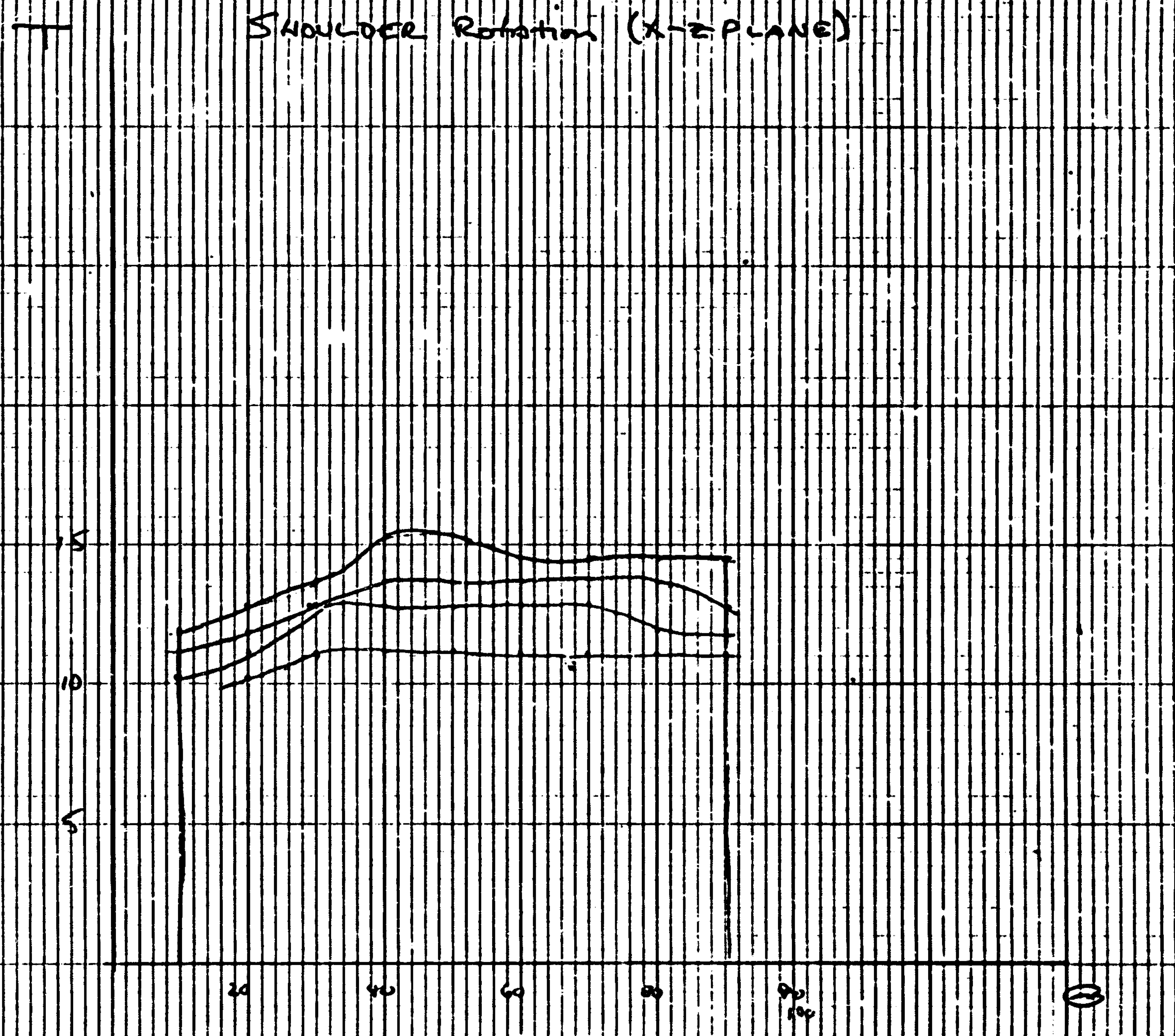


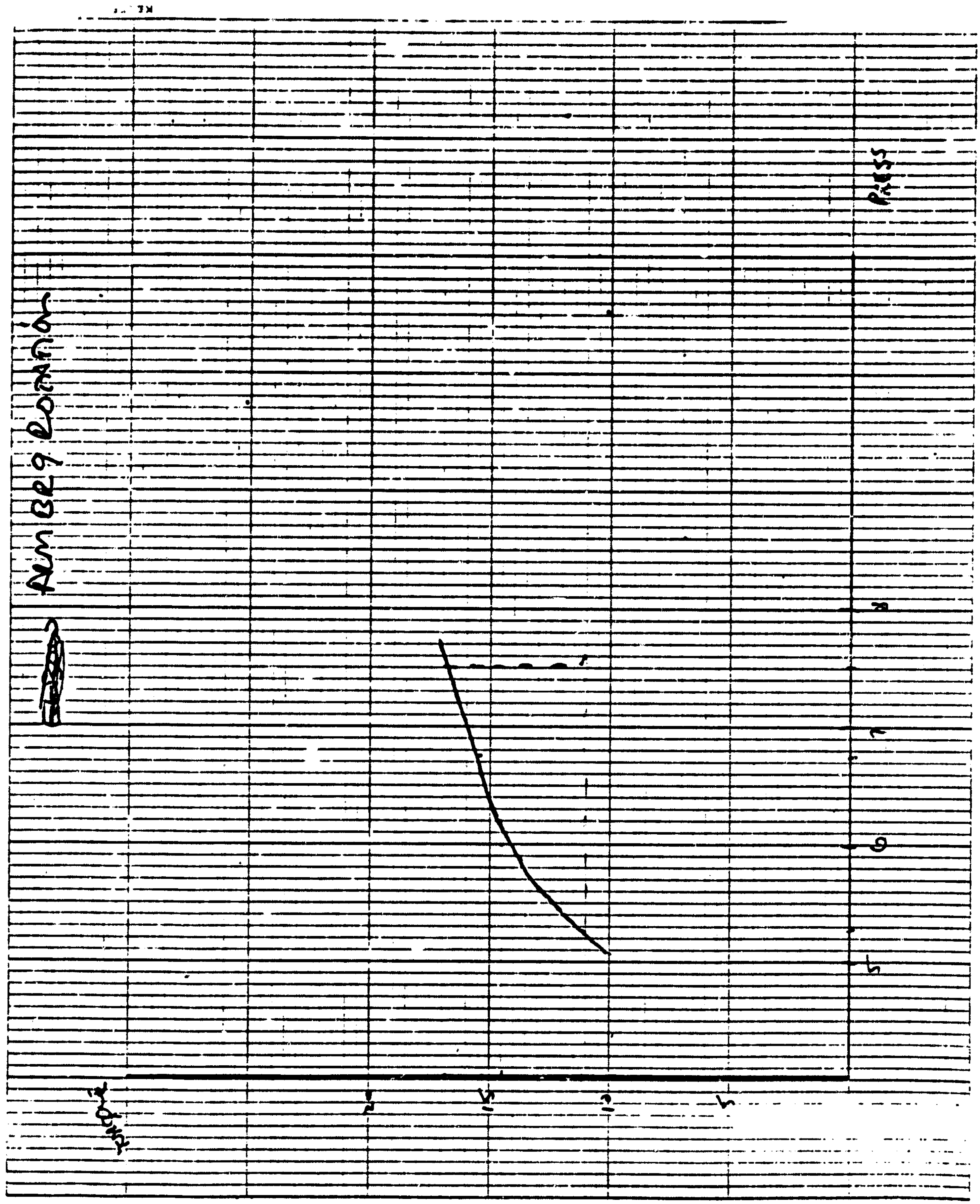



B


SC-1C BRG
TORQUE
40
30
20
10
1
2
3
4
5
6
7
PRESS

ARM E??





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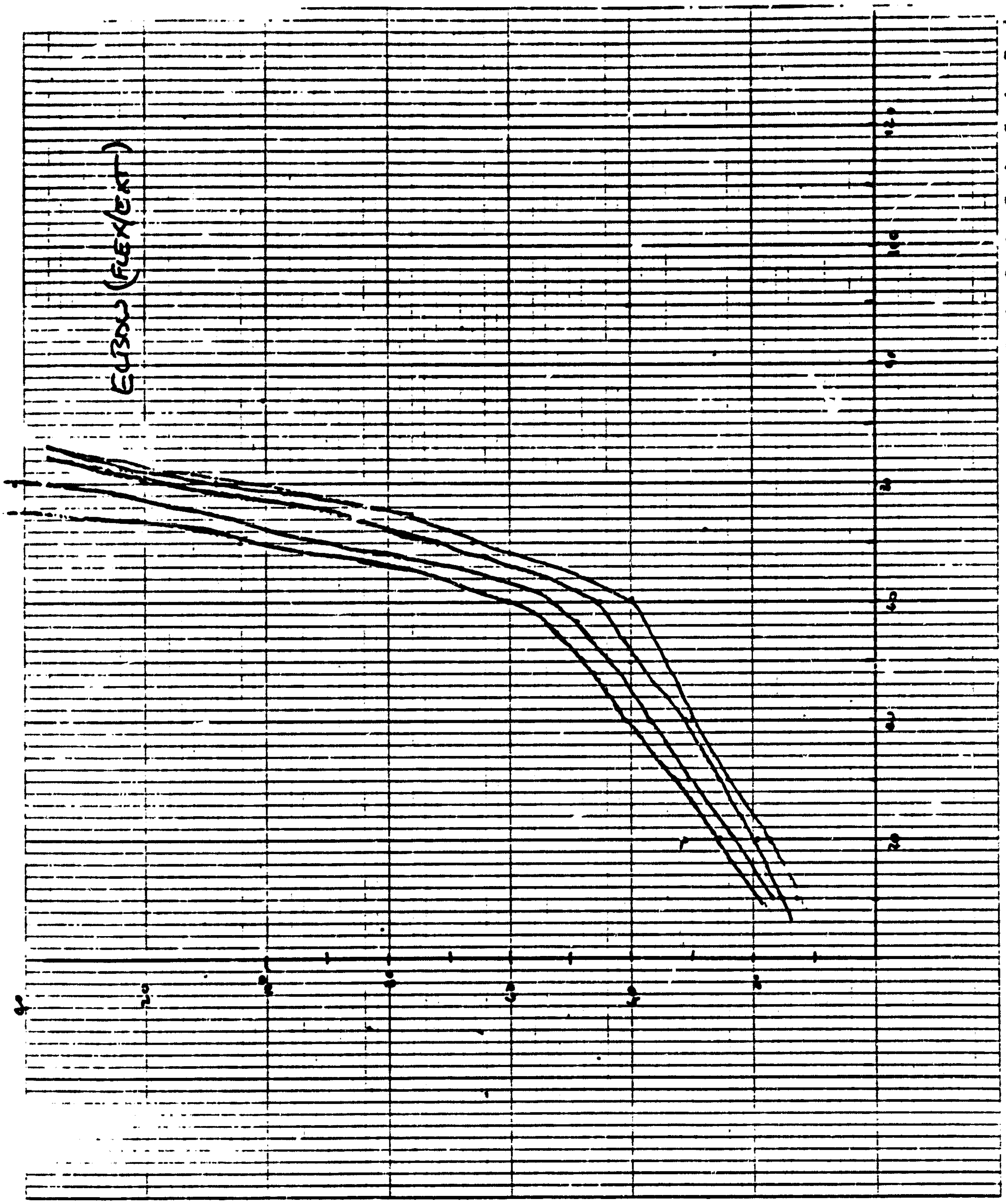
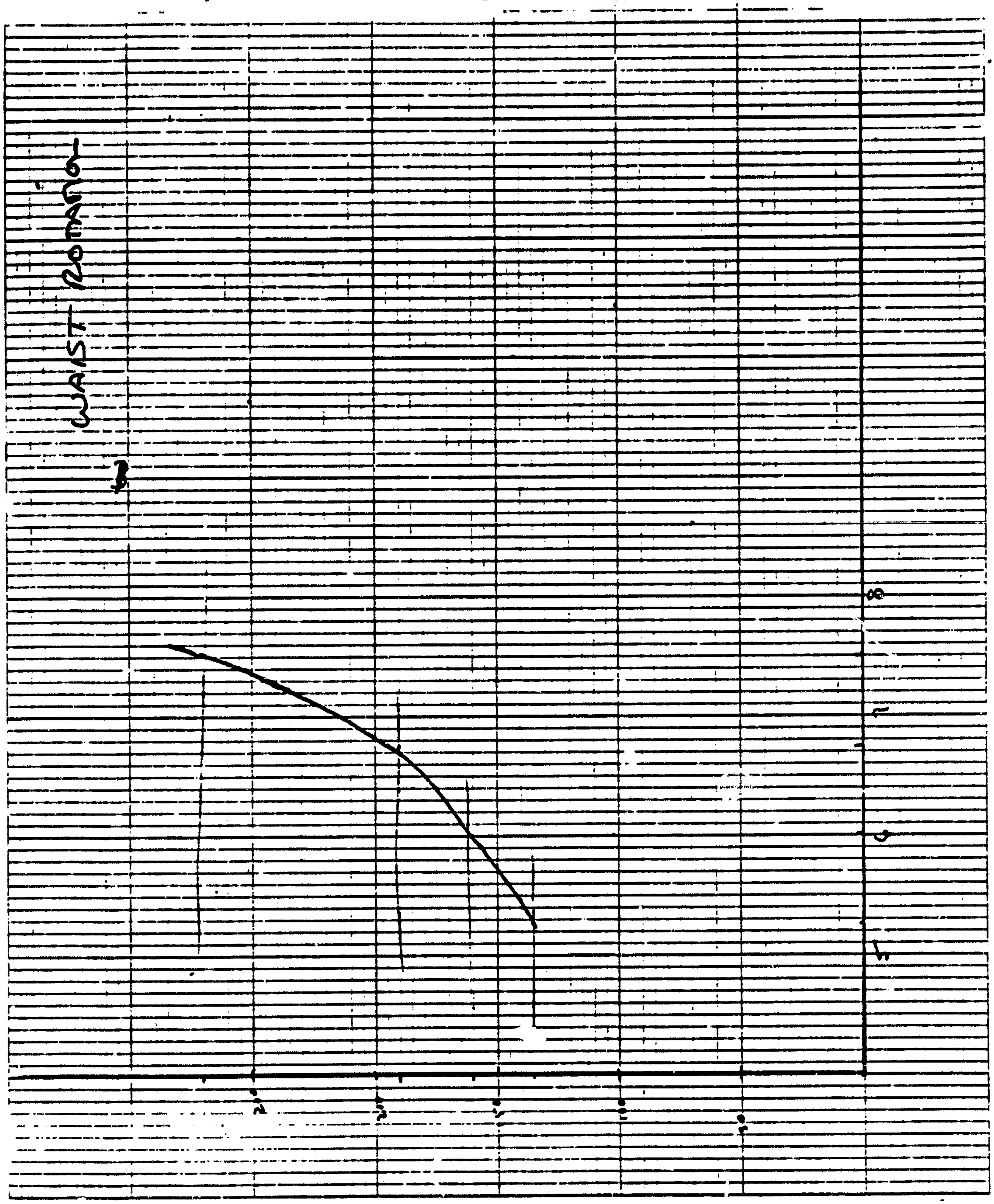
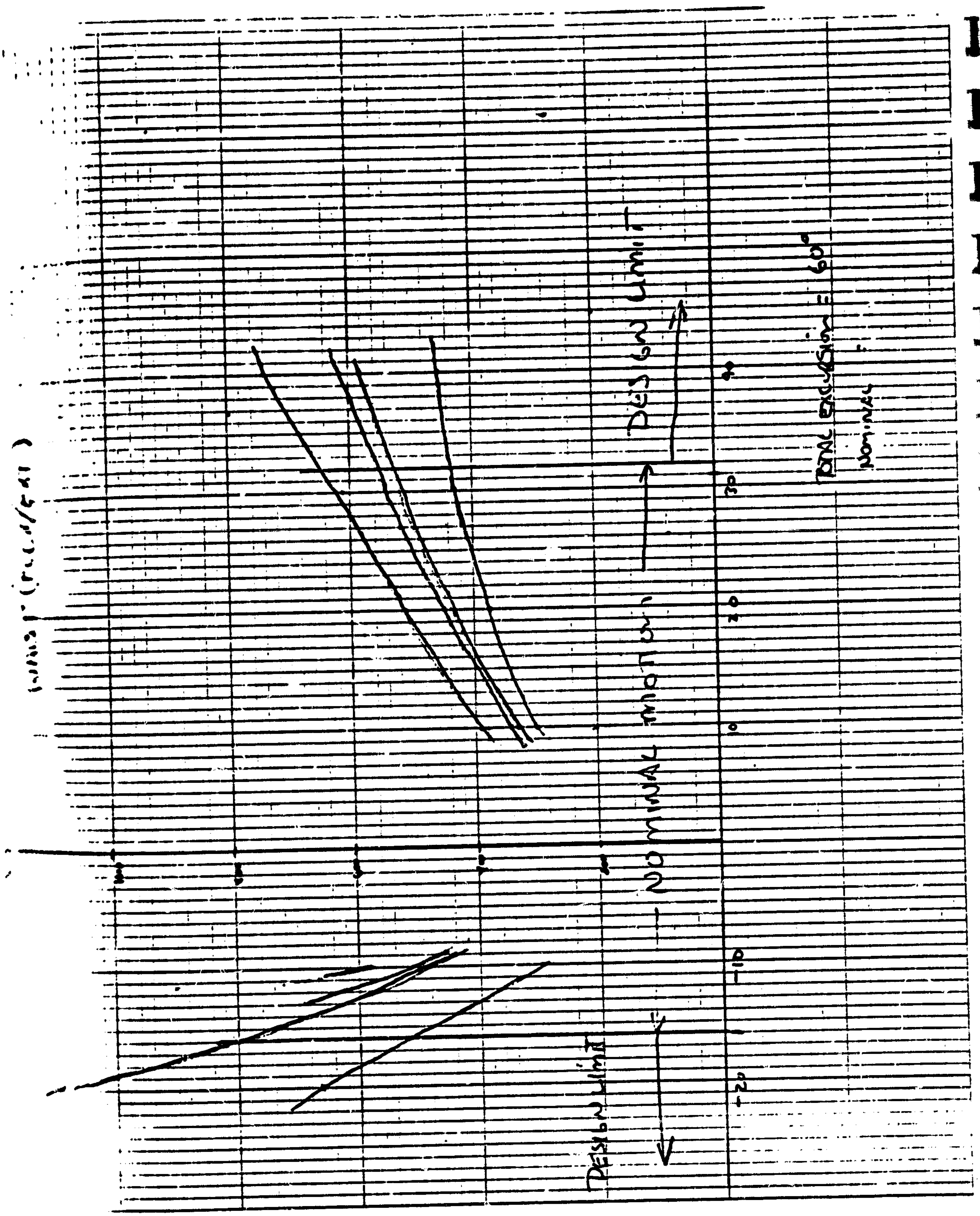
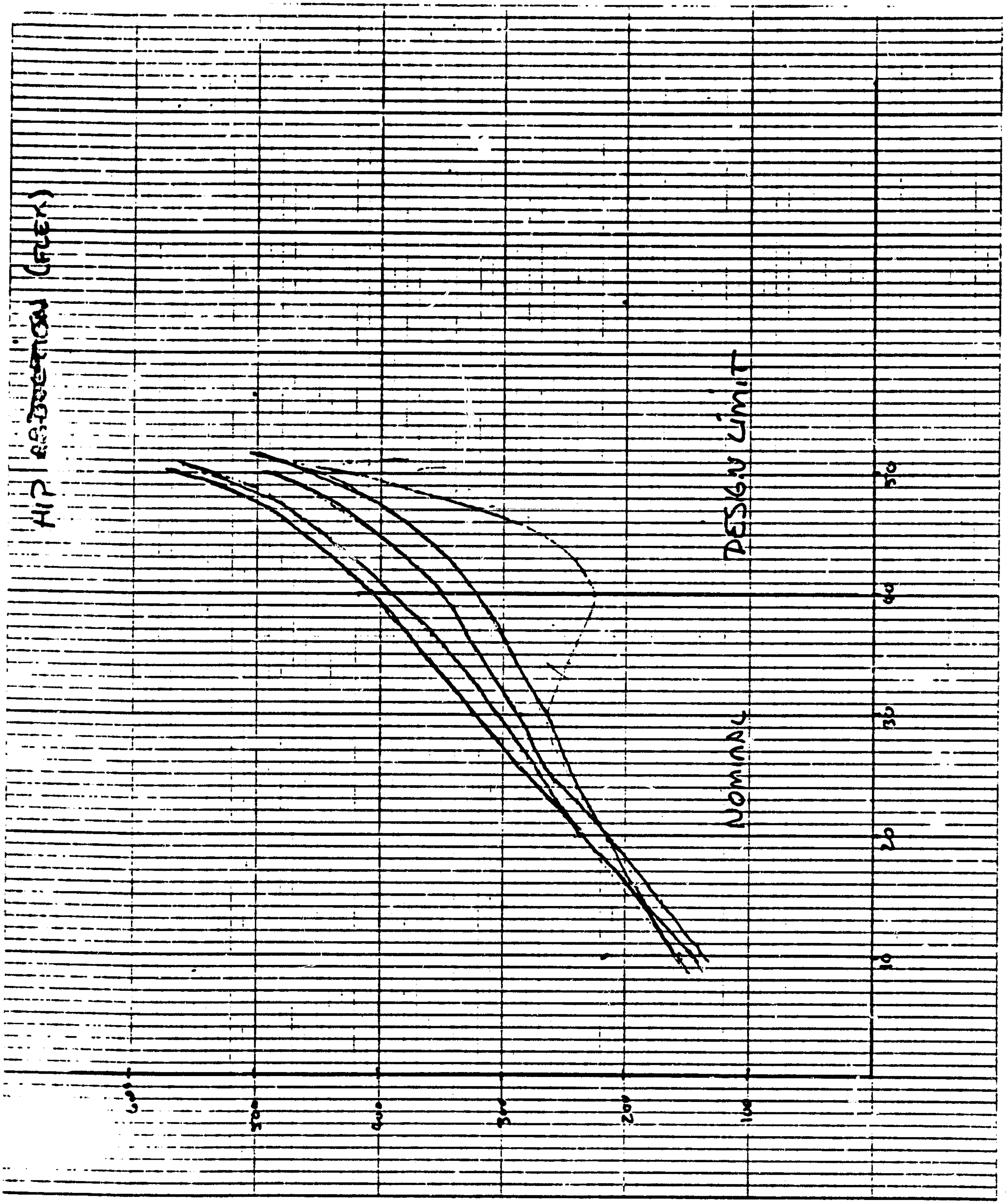
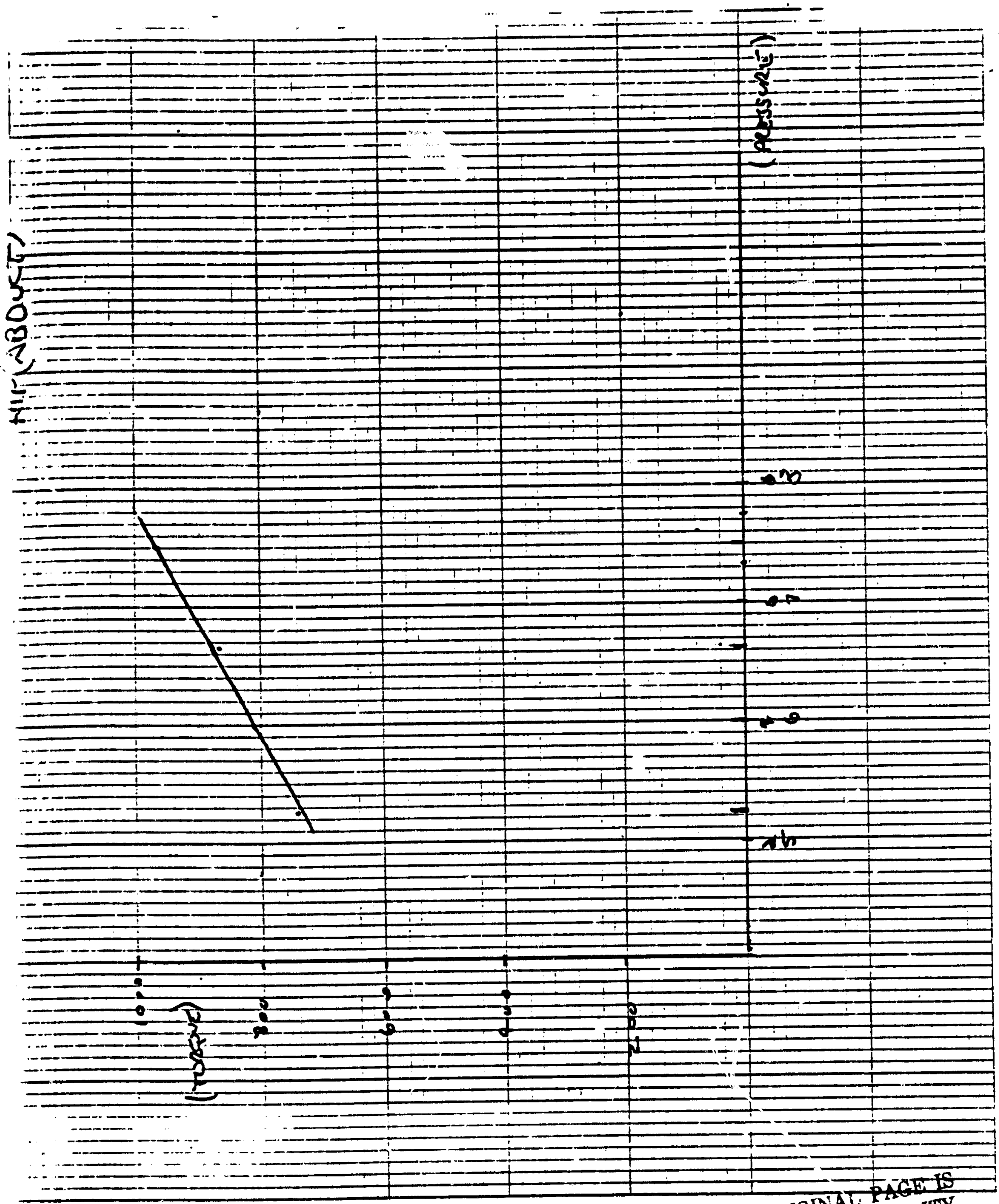

ELBOW (FLEX/EXT)




17


DESIGN LIMIT
NOMINAL MOTION
DESIGN LIMIT
TOTAL EXCURSION = 60°
NOMINAL
-20
-10
0
10
20
30
40


DESIGN LIMIT
NOMINAL
10
20
30
40
50
100
200
300
400
500

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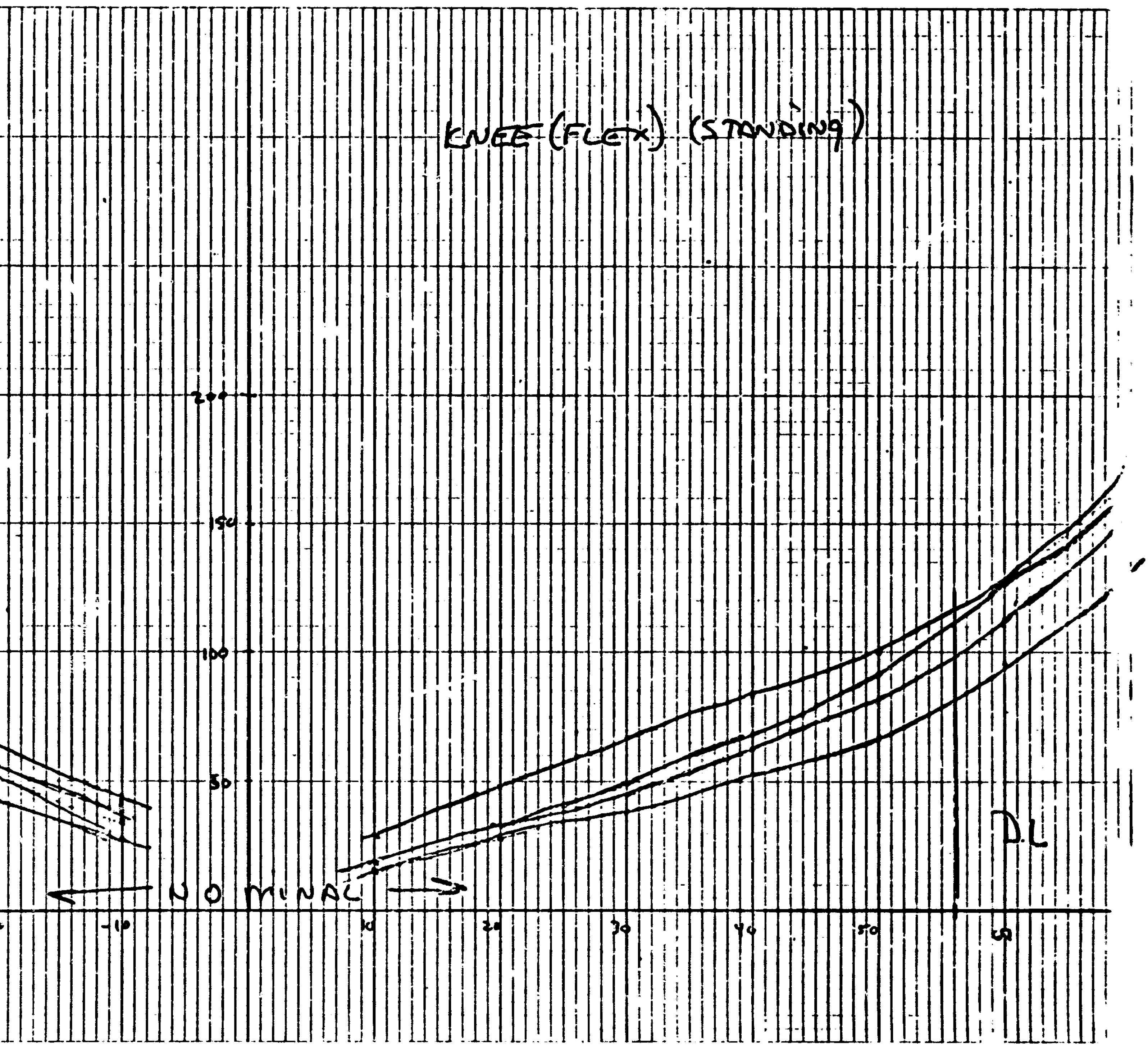
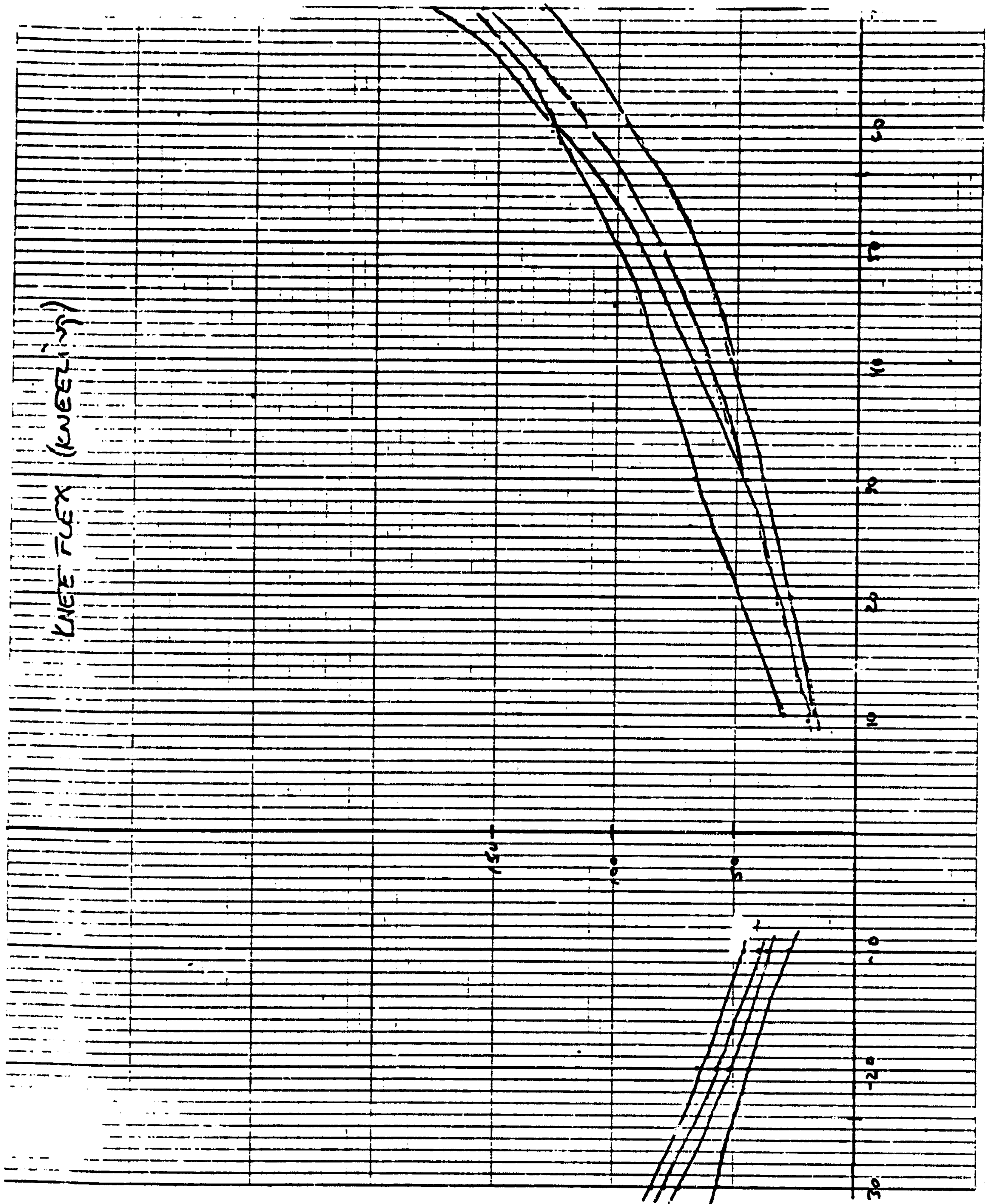
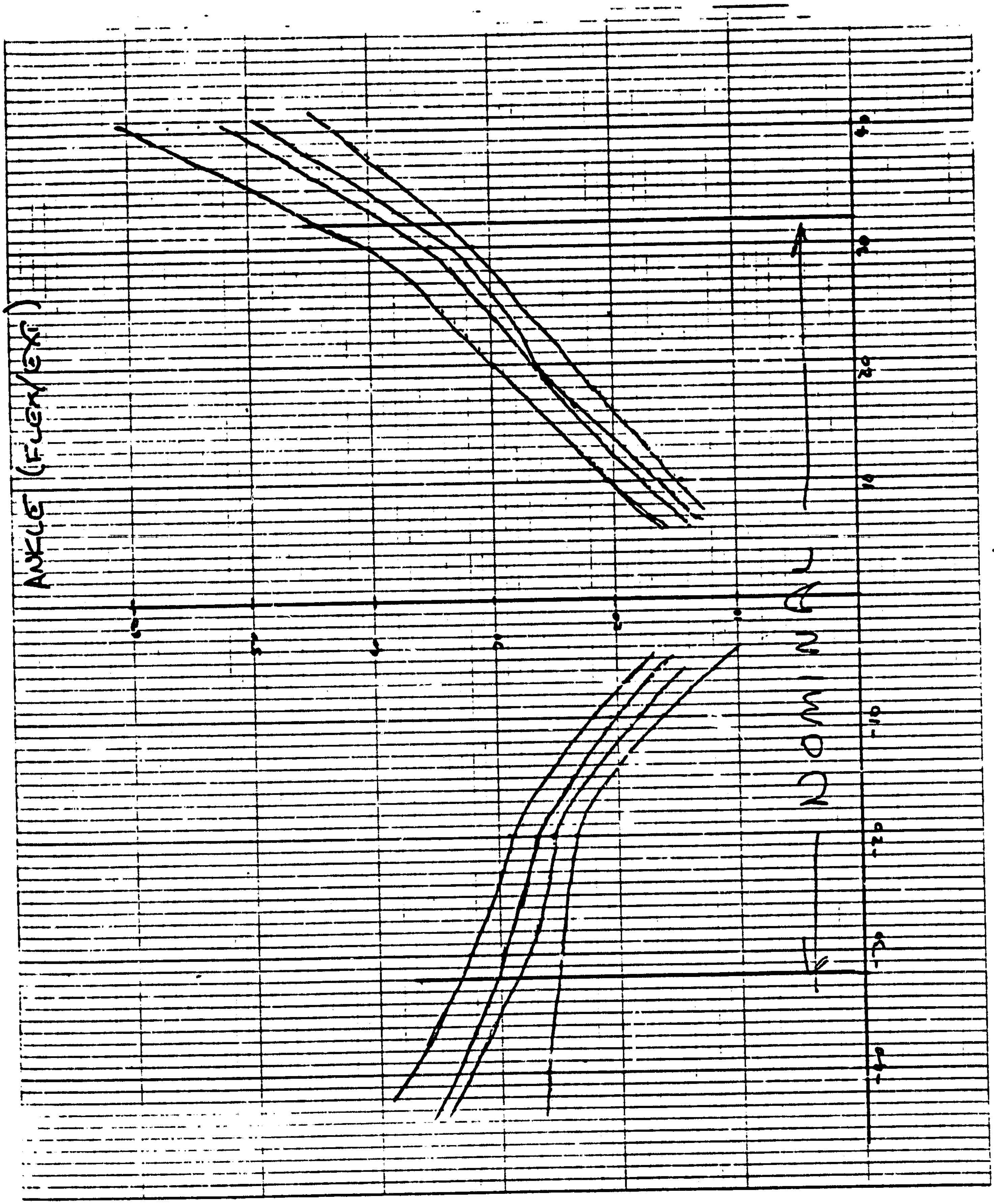


KNEE (FLEX) (STANDING)
200
150
100
50
D.L
NOMINAL
-10
10
20
30
40
50
60


KNEE FLEX (KNEELING)
150
100
50
40
20
10
-20
-30


ANKLE (FLEX/EXT)
UP
DOWN
40
30
20
10
-10
-20
-30
-40